CRC Report: ACES Phase 1

PHASE 1 OF THE ADVANCED COLLABORATIVE EMISSIONS STUDY

June 2009

COORDINATING RESEARCH COUNCIL, INC.
3650 MANSELL ROAD·SUITE 140·ALPHARETTA, GA 30022

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Research described in this report was conducted under contract to the Health Effects Institute (HEI), and was made possible, in part, through support provided by the United States Department of Energy (DOE), under the terms of Contract/Award Number DE-AC26-05NT42429, and certain motor vehicle and engine manufacturers. The opinions expressed herein are those of the author(s) and do not necessarily reflect the views of HEI, or its sponsors, nor do they necessarily reflect the views of DOE or motor vehicle and engine manufacturers.

PHASE 1 OF THE ADVANCED COLLABORATIVE EMISSIONS STUDY

FINAL REPORT

SwRI® Project No. 03.13062

Prepared for and Sponsored by:

Coordinating Research Council, Inc.
3650 Mansell Road, Suite 140
Alpharetta, GA 30022

Health Effects Institute
101 Federal Street, Suite 500
Boston, MA 02110

Funded by:

Department of Energy, Office of Vehicle Technologies
Environmental Protection Agency
Engine Manufacturers Association
California Air Resources Board
American Petroleum Institute
Corning Inc.
ArvinMeritor

Prepared by:

Imad A. Khalek, Program Manager
Thomas L. Bougher, Research Engineer
Patrick M. Merritt, Senior Research Scientist

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Prepared by:	Reviewed by:
Imad A. Khalek, Program Manager	Jeff J. White, Director

EMISSIONS RESEARCH AND DEVELOPMENT DEPARTMENT
ENGINE, EMISSIONS AND VEHICLE RESEARCH DIVISION

FOREWORD

Phase 1 of the Advanced Collaborative Emissions Study (ACES Phase 1) was performed by SwRI's Emissions Research and Development Department (ER&DD), in the Engine, Emissions and Vehicle Research Division.

SwRI's Principal Investigator and Project Manager was Dr. Imad Khalek, Program Manager. SwRI's Project Leader was Mr. Thomas Bougher, Research Engineer. The chemistry effort was coordinated by Mr. Patrick Merritt, Senior Research Scientist. Chemistry assistance was provided by Mr. Ken Jones, Senior Research Technologist, Mr. Tom Gabehart, Research Technologist, Ms. Yolanda Rodriguez, Staff Technician, Ms. Kelly Strate, Senior Technician, Mr. Chuan-Yi Tsai, Research Assistant, and Mr. Luis Sanchez, Principal Technician. Additional assistance was provided by Ms. Jacqueline Ranger, Group Leader, and Ms. Shraddha Quarderer, Senior Research Scientist. Laboratory assistance was provided by Mr. Ernie Krueger, Laboratory Manager, Mr. Keith Echtle, Assistant Manager, Mr. Danny Terrazas, Supervisor, Mr. Daniel Preece, Senior Technician, Mr. William Valuk, Staff Technician, Mr. Don Parker, Senior Technician, Mr. Joe Sosa, Principal Technician, Mr. Rudy Guerra, Senior Technician, Mr. Denny Zaske, Senior Technician, and Mr. Tim Milligan, Principal Technician.

Chemical analyses were performed by SwRI's ER&DD and SwRI's Chemistry and Chemical Engineering Division. Additional chemical analyses such as PAHs, polar compounds, elements, and OC/EC were performed by Desert Research Institute (DRI), with Dr. Barbara Zielinska as the Principal Investigator.

ACES Phase 1 was sponsored by CRC and HEI, with funding from the DOE Office of Vehicle Technologies, EPA, EMA, CARB, API, Corning Inc., and ArvinMeritor. The engines and engine support were provided by Caterpillar, Cummins, Detroit Diesel, and Volvo Powertrain. Key contacts were Mr. Reynaldo Agama, Caterpillar, Dr. Shirish Shimpi, Cummins, Mr. Don Keski-Hynnila, Detroit Diesel, and Mr. Steve Berry, Volvo Powertrain. The lube oil was provided by Lubrizol, and the key contact was Dr. Ewa Bardasz.

The sponsors' project coordinators were Dr. Chris Tennant from CRC and Dr. Maria Costantini from HEI. The CRC ACES Panel members included:

Mr. Reynaldo Agama, Caterpillar
Dr. James Ball, Ford Motor Company (now retired)
Dr. Nicholas Barsic, John Deere
Mr. Steve Berry, Volvo Powertrain
Dr. Steven Cadle, General Motors R&D Center (now retired)
Dr. Maria Costantini, Health Effects Institute
Dr. Annemoon van Erp, Health Effects Institute
Mr. Timothy French, Engine Manufacturers Association
Dr. Thomas Hesterberg, Navistar
Mr. Donald Keski-Hynnila, Detroit Diesel
Mr. Chris Laroo, US Environmental Protection Agency
Dr. Douglas Lawson, National Renewable Energy Laboratory
Mr. Hector Maldonado, California Air Resources Board

Dr. Matti Maricq, Ford Motor Company
Dr. Mani Natarajan, Marathon Petroleum Company LLC
Mr. Ralph Nine, US Department of Energy/National Energy Technology Laboratory
Dr. Robert Okamoto, California Air Resources Board
Mr. Charles Schleyer, ExxonMobil
Dr. Shirish Shimpi, Cummins
Dr. Joseph Somers, US Environmental Protection Agency
Dr. Chris Tennant, Coordinating Research Council
Mr. Steve Trevitz, Volvo Powertrain
Dr. Urban Wass, Volvo AB
Dr. Jane Warren, Health Effects Institute (now retired)

EXECUTIVE SUMMARY

Phase 1 of the Advanced Collaborative Emissions Study (ACES) included detailed chemical characterization of exhaust species emitted from four 2007 model-year heavy heavy-duty diesel engines (HHDDE) manufactured by Caterpillar, Cummins, Detroit Diesel, and Volvo. The work started in March, 2007, and was completed in August, 2008. ACES Phase 1 objectives were:

- To quantify the reduction in both regulated and unregulated emissions from advanced diesel engines,
- To provide regulated and unregulated emissions data for this new engine technology,
- Make data available to support the selection of one engine for the ACES Phase 3 health study,
- To provide initial guidance for the ACES Phase 3 health study using the regulated and unregulated emissions information from ACES Phase 1.

Based on the results of the exhaust emissions characterization, one of the four ACES engines, Engine B, was selected for the ACES Phase 3 health study to be conducted at Lovelace Respiratory Research Institute (LRRI). The engine selection process is described in a Health Effects Institute (HEI) Report, included in Appendix A. An additional backup engine to the one selected for the health study, Engine B', was provided by the engine manufacturer and was tested for regulated emissions at a barometric pressure of 99.3 kPa, representing SwRI's elevation in San Antonio, Texas, and at a simulated barometric pressure of 82.6 kPa, representing LRRI's higher elevation in Albuquerque, New Mexico. The high elevation simulation was performed on the backup engine only.

To comply with 2007 EPA regulations, each engine tested was equipped with water-cooled exhaust gas recirculation (EGR) or clean gas induction (CGI) to reduce NO_x emissions, along with a catalyzed diesel particulate filter (C-DPF), or a diesel oxidation catalyst (DOC) followed by a C-DPF to reduce PM emissions. DOCs were mainly used to increase nitrogen dioxide production to promote the oxidation of soot deposited in the C-DPF. Furthermore, a diesel fuel burner located upstream of the C-DPF, or a diesel fuel injector located upstream of the DOC, was used to elevate exhaust temperature at the inlet of the C-DPF to actively regenerate and clean the C-DPF, as needed. Numerous additional improvements were also made by each engine manufacturer to engine boost pressure and its response, fuel injection and combustion management, and system integration. Manufacturers also equipped engines with crankcase ventilation systems with filters to reduce PM emissions from the crankcase blow-by, which was vented to the atmosphere.

ACES engines emissions were characterized on the following test cycles:

- FTP, the basis for US EPA engine certification and audit.
- CARBx-ICT, idle, creep and a transient portion of the CARB HHDDE-5 Modes (CARB 5-Modes).
- CARBz-CH, cruise and high speed cruise of the CARB 5-Modes.

- 16-Hour Cycle, four 4-hour segments consisting of FTPs and CARB 5-Modes. (The 16-Hour cycle was developed mainly to be used in ACES Phase 1 and in the Phase 3 health study.)

For reference, the CARB 5-Modes were developed earlier by CARB and include curb idle, creep, transient, cruise, and high speed cruise modes.

Table ES-1 provides a summary of cycle time, average exhaust temperature, and percent power relative to the Federal Test Procedure (FTP) transient cycle.

TABLE ES-1. SUMMARY OF CYCLES TESTED

Test Cycles	Time, min	Average Exhaust Temperature, °C	% of FTP Average Power
FTP	20	243	100
CARBx-ICT	39	131	20
CARBz-CH	49	297	137
16-Hour [a]	960	277	110
[a] Four 4-hour segments that consist of repeats of the FTP and CARB-5 Modes			

For each cycle used, regulated emissions of carbon monoxide (CO), non-methane hydrocarbons (NMHC), oxides of nitrogen (NO_x), and particulate matter (PM), were measured. Unregulated emissions measured included total hydrocarbon (THC), methane (CH_4), carbon dioxide (CO_2), nitric oxide (NO), nitrogen dioxide (NO_2), nitrous oxide (N_2O), particle size and number, organic carbon (OC), elemental carbon (EC), metals and elements, polynuclear aromatic hydrocarbons (PAH), nitroPAH, oxyPAH, polar compounds, alkanes, hopanes, steranes, cyanide ion, organic acids, gas phase acids, nitrosamines, detailed speciation of C_2 – C_{12} hydrocarbons, aldehydes and ketones, and dioxins/furans (only for the 16-Hour cycle).

Samples of the different exhaust species were taken either directly from the sample zone of the full-flow constant volume sampler (CVS) dilution tunnel, or from locations that were linked to the sample zone by a dilution step with a dilution ratio of about 2. A unique sample location employed was an animal exposure chamber (unoccupied), provided by LRRI, to determine concentration levels that might be expected in ACES Phase 3. Real time particle size and number, total PM, soot and OC/EC measurements were taken from the exposure chamber.

All measurements were performed with engine blow-by routed to the exhaust downstream of the C-DPF. Selected FTP tests without blow-by were also performed.

Table ES-2 summarizes the average FTP regulated emissions with blow-by relative to EPA 2007 standards. Based on the average emissions from all four ACES engines, PM, CO, and NMHC emissions were all at least 90 percent below the EPA standard. Average NO_x emissions were 10 percent below the standard.

FTP transient cycle average PM emissions without blow-by were 38 percent lower than that with blow-by. For the high elevation testing performed with the backup engine, NO_x emissions were about 34 percent higher than at normal elevation.

TABLE ES-2. SUMMARY OF AVERAGE REGULATED EMISSIONS BASED ON THE FTP CYCLE WITH BLOW-BY

	2007 EPA Standard (g/hp-hr)	Average ACES Engine Emissions (g/hp-hr)	ACES Emissions % Reduction Relative to the 2007 Certification Standard
CO	15.5	0.33	98
NMHC	0.14	0.0064	95
PM	0.01	0.0011	89
NO_X	1.2 [a]	1.075	10
[a] Average value between 2007 and 2009, with full enforcement in 2010 at 0.20 g/hp-hr			

Average FTP NO_2 emissions for the four ACES engines, were 0.73 g/hp-hr, with an NO_2 to NO_x ratio of 68 percent. The NO_2 to NO_X ratio for 2004 technology engines is typically lower, at 4 to 15 percent of the 2004 NO_X limit of 2.4 g/hp-hr. Thus, the direct NO_2 emissions from these ACES engines can be a factor of two to eight times higher than from 2004 technology engines, although the total NO_x emissions from the ACES engines are lower. This increase in NO_2 emissions from 2007 and later heavy-duty diesel engines is temporary, and is expected to be reduced below the EPA 2010 NO_x limit of 0.2 g/hp-hr when 2010 engines are introduced.

During active regeneration, real time particle number emissions from 5.6 nm to 30 nm in diameter can be several orders of magnitude higher than the concentration without active regeneration. However, as shown in Figure ES-1, even when active regeneration occurred, the average particle number emissions were low -- on the order of 90 percent below the level emitted by a 2004 technology engine. They were a factor of 10 higher than the average emissions without regeneration, in spite of the low frequency of occurrence of active regeneration during the 16-Hour cycle (1 to 3 times per 16-Hour cycle).

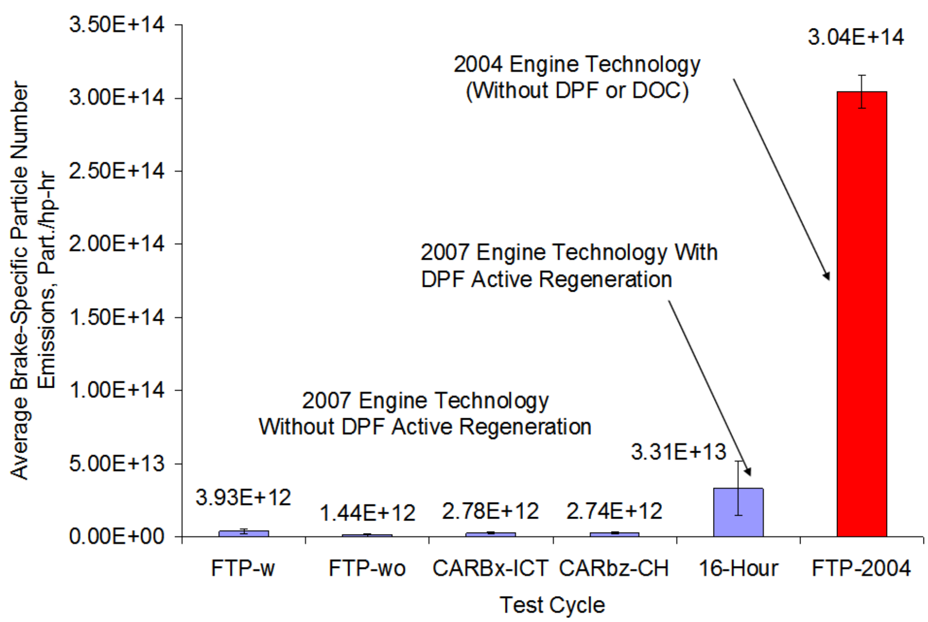

FIGURE ES-1. AVERAGE PARTICLE NUMBER EMISSIONS (W AND WO REPRESENT "WITH" AND "WITHOUT" ENGINE BLOW-BY, RESPECTIVELY)

Unregulated compounds in Table ES-3 show reductions relative to a 2004 technology engine used in the CRC E55/59 [1] study, and also relative to a 1998 technology engine [2] for dioxins/furans. Reductions ranged from 38 percent for inorganic ions to 99 percent for hopanes/steranes, elemental carbon, and dioxins/furans. No vanadium emissions were detected in the ACES engines, but copper emissions were detected during the 16-Hour cycle.

TABLE ES-3. SUMMARY OF UNREGULATED EMISSIONS REDUCTION FOR 16-HOUR CYCLE

Compounds	% Reduction Relative to 2004 Technology Engine
Single Ring Aromatics	82
PAH	79
NitroPAH	81
Alkanes	85
Polar	81
Hopanes/Steranes	99
Carbonyls	98
Inorganic Ions	38
Metals and Elements	98
Organic Carbon	96
Elemental Carbon	99
Dioxins/Furans [a]	99
[a] Relative to 1998 technology engine	

2007 technology engine PM was composed mainly of sulfate and organic carbon, with a small fraction of elemental carbon and metals and elements, as shown in Figure ES-2.

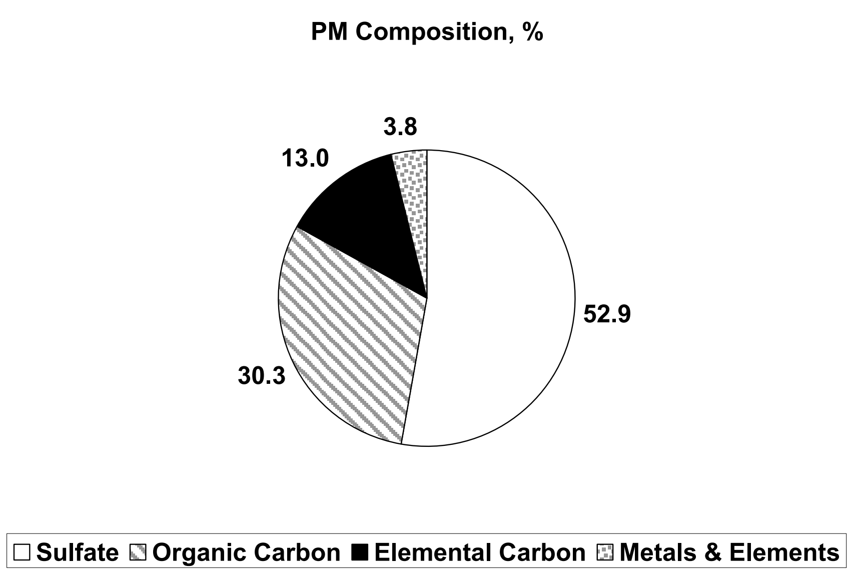

FIGURE ES 2. MEASURED PM COMPOSITION FOR 16-HOUR CYCLE

In summary, the ACES engines achieved more than 89 percent reductions in NMHC, CO, and PM emissions compared to the 2007 standards. Unregulated emissions were also substantially reduced relative to a 2004 technology engine. ACES engines NO_2 emissions were higher than those from 2004 technology engines due to the use of DOC and C-DPF technology. NO_2 emissions will likely be considerably reduced when 2010 engines are introduced.

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ACRONYMS AND ABBREVIATIONS

ACES	Advanced Collaborative Emissions Study
API	American Petroleum Institute
BG	Background (clean dilution air downstream of the HEPA filter of the full flow constant volume sampler tunnel)
BSE	Brake-Specific Emissions
BSFC	Brake Specific Fuel Consumption
CARB	California Air Resources Board
CARB 5-Modes	CARB Heavy Heavy-Duty Idle, Creep, Transient, Cruise, and High Speed Cruise modes
CARBx-ICT	Idle, Creep, and Transient of CARB 5-Modes
CARBz-CH	Cruise and High Speed Cruise of CARB 5-Modes
CFR	Code of Federal Regulations
CGI	Clean Gas Induction
CI	Chemical Ionization
CO	Carbon Monoxide
CRC	Coordinating Research Council
CVAAS	Cold Vapor Atomic Absorption Spectroscopy
CVS	Constant Volume Sampler
DCM	Dichloromethane
DMM	Dekati Mass Monitor
DNPH	Dinitrophenylhydrazine
DOE	Department of Energy
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
DR	Dilution Ratio
DRI	Desert Research Institute
DFI/GC	Direct Filter Injection Gas Chromatography
EC	Elemental Carbon
ECM	Engine Control Module
EDXRF	Energy Dispersive X-Ray Fluorescence
EEPS	Engine Exhaust Particle Sizer
EGR	Exhaust Gas Recirculation
EI	Electron Impact
EMA	Engine Manufacturers Association
EPA	Environmental Protection Agency
ER&DD	Emissions Research and Development Department
FD	Fuel Density
FID	Flame Ionization Detector
FM	Fuel Mileage
FTIR	Fourier Transform Infrared Spectroscopy
FTP	Federal Test Procedure
FTP-TC	Federal Test Procedure Transient Cycle
FTP-w	Federal Test Procedure Transient Cycle with Blow-By
FTP-woo	Federal Test Procedure Transient Cycle without Blow-By
GC-ECD	Gas Chromatography-Electron Capture Detection
GC/MS	Gas Chromatograph/Mass Spectroscopy

HDDE	Heavy-Duty Diesel Engine
HEI	Health Effects Institute
HEPA	High Efficiency Particulate Air
HHDDE	Heavy Heavy-Duty Diesel Engine
HPLC	High Performance Liquid Chromatography
HRGC	High Resolution Gas Chromatography
HRMS	High Resolution Mass Spectroscopy
VOC	Volatile Organic Compounds
IC	Ion Chromatography
ICP/MS	Inductively Coupled Plasma/Mass Spectroscopy
LRRI	Lovelace Respiratory Research Institute
MID	Multiple Ion Detection
N/A	Not Available
MSS	Micro-Soot Sensor
NDIR	Non-Dispersed Infrared
NIST	National Institute of Standards and Technology
NitroPAH	Nitrated Polycyclic Aromatic Hydrocarbon
NMHC	Non-Methane Hydrocarbon
NO	Nitric oxide
NO_2	Nitrogen Dioxide
N_2O	Nitrous Oxide
NO_X	Oxides of Nitrogen
OC	Organic Carbon
ODS	Octadecasilane
POC	Principle Organic Constituents
OxyPAH	Oxygenated Polycyclic Aromatic Hydrocarbon
PAH	Polycyclic Aromatic Hydrocarbon
PCDD	Polychlorinated Dibenzodioxins
PCDF	Polychlorinated Dibenzofurans
PM	Particulate Matter
PTFE	Polytetrafluoroethylene
PUF	Polyurethane Foam
SIS	Selective Ion Storage
S/N	Signal to Noise
SRM	Standard Reference Material
SVOC	Semivolatile Organic Compound
SwRI	Southwest Research Institute
TB	Tunnel Blank
TEF	Toxic Equivalency Factor
TEQ	Toxic Equivalent
THC	Total Hydrocarbon
TOR	Thermal Optical Reflectance
TOT	Thermal Optical Transmittance
ULSD	Ultra-low Sulfur Diesel
UV	Ultraviolet
VOST	Volatile Organic Sample Train
XAD™	"Polymeric Adsorbing Resins"
XRF	X-Ray Fluorescence

1.0 INTRODUCTION

Four heavy-duty diesel engine manufacturers, Caterpillar (CAT), Inc., Cummins, Inc., Detroit Diesel Corporation (DDC), and Volvo Powertrain, provided engines for Phase 1 of the ACES program. The engines were all 2007 model-year and included a CAT C13, Cummins ISX, DDC Series 60, and a Mack MP7. All four engines are considered to be heavy heavy-duty diesel engines that are currently being marketed in the US. The exhaust composition of these engines was characterized to verify that the concentration of regulated emissions were at or below the requirements of EPA's 2007 regulation and to provide data on emission concentrations of a large number of unregulated compounds. One of the four engines was selected for ACES Phase 3 exposure study based on ACES Phase 1 emission results, and according to the process described in Appendix A.

A backup engine to the one selected for ACES Phase 3 exposure study was provided by one of the manufacturers for regulated emissions testing at SwRI's elevation in San Antonio, Texas, (99.3 kpa), and at a simulated high elevation (82.6 kpa), similar to that of LRRI in Albuquerque, New Mexico, where the ACES Phase 3 exposure study will be conducted.

Throughout the ACES project, all engines have remained anonymous, and were designated as Engine A, Engine B, Engine C, Engine D, and Engine B' for the backup engine. It is understood that the identity of these engines will be revealed by CRC, after the ACES exposure study is completed.

The four primary engines (Engines A, B, C, and D) were tested for regulated and unregulated emissions, at SwRI's elevation, using the hot-start Federal Test Procedure transient cycle (FTP-TC), two composites of the CARB Heavy Heavy-Duty Diesel Engines (HHDDE) 5-Modes (CARB 5-Modes), and a 16-Hour transient cycle that was developed by West Virginia University for this program. This cycle was composed of the FTP-TC and the CARB 5-Modes [3]. The backup engine, Engine B', was tested for regulated emissions using the FTP-TC at SwRI's elevation and at LRRI's simulated elevation.

Regulated emissions measurement included carbon monoxide (CO), non-methane hydrocarbon (NMHC), oxides of nitrogen (NO_x), and particulate matter (PM). Unregulated emissions included total hydrocarbon (THC), methane (CH_4), carbon dioxide (CO_2), nitric oxide (NO), nitrogen dioxide (NO_2), particle size and number, organic carbon, elemental carbon, metals and elements, polynuclear aromatic hydrocarbon (PAH), nitroPAH, oxyPAH, polar compounds, alkanes, hopanes, steranes, cyanide ion, organic acids, gas phase acids, nitrosamines, detailed speciation of $C_2 – C_{12}$ hydrocarbons, aldehydes and ketones, and dioxins and furans.

All volumetric flows, volumes or concentrations shown in this report are based on a reference temperature of 20^{o}C and a pressure of 101.3 kPa, used in 40 CFR Part 86. All averages, standard deviations, and error bars are based on three repeats of the FTPs, two repeats of CARBx-ICT, two repeats of the CARBz-CH, and three repeats of the 16-Hour cycle.

2.0 EXPERIMENTAL SETUP

2.1 Engines

Five 2007 model-year (MY 2007) HHDDEs were used in Phase 1 of the ACES program. One of the five engines was a duplicate backup engine. The engines included a CAT C13, Cummins ISX, DDC Series 60, and Mack MP7, as shown in Figures 1, 2, 3, and 4, respectively. All engines were equipped with a diesel oxidation catalyst (DOC) followed by a wall-flow catalyzed diesel particulate filter (DPF), or simply with a catalyzed DPF with a means of active regeneration via exhaust fuel injection or a burner. All engines were turbocharged with water-cooled intake air systems. Three of the engines were equipped with water-cooled high-pressure loop exhaust gas recirculation (EGR), where the exhaust gas is routed from before the DPF to the high pressure side of the intake air compressor. One engine was equipped with low-pressure loop water-cooled EGR or clean gas induction (CGI), where the exhaust gas is routed from downstream of the DPF to the inlet side of the intake air compressor.

The active regeneration strategy for each engine was different and may take into consideration such things as engine operating time, fuel used, DPF loading condition, DOC inlet temperature, DPF inlet temperature, and sophisticated accountability, soot loading, and other factors such as occurrence of passive regeneration during normal operation. All active regeneration events were triggered by the engine control module (ECM), without any interference by the engine operator, except during exhaust system conditioning, where the DPF went into a "forced" active regeneration event that was triggered by the engine operator.

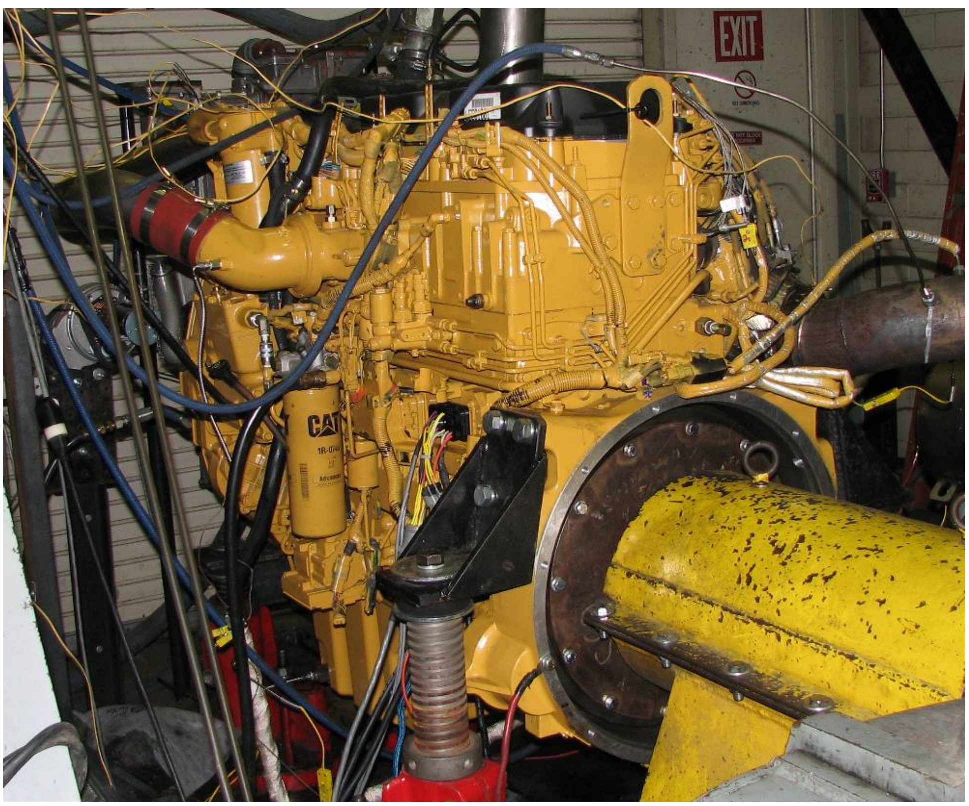


FIGURE 1. 2007 CATERPILLAR C13 ENGINE

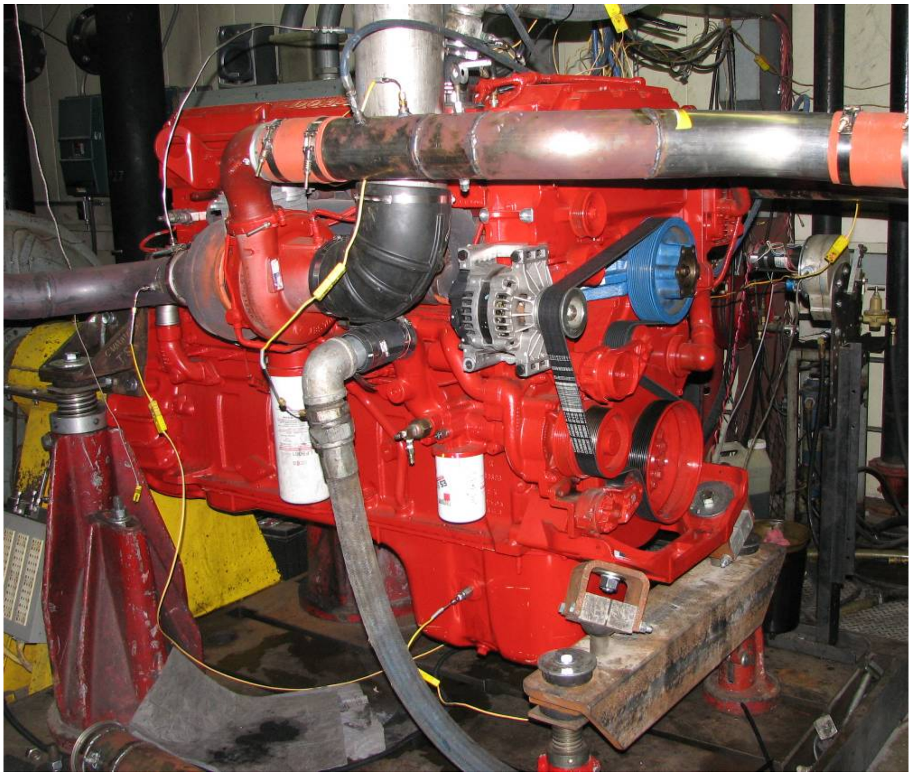


FIGURE 2. 2007 CUMMINS ISX ENGINE

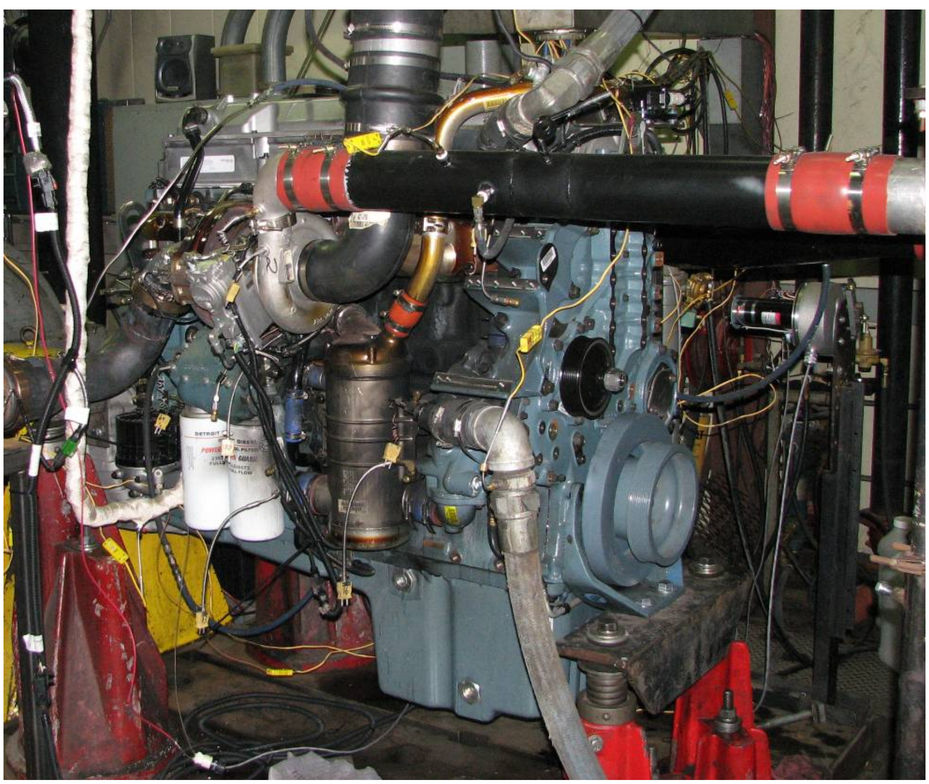


FIGURE 3. 2007 DETROIT DIESEL DDC SERIES 60 ENGINE

FIGURE 4. 2007 VOLVO POWERTRAIN MACK MP7

2.2 Fuel and Oil Properties

2.2.1 Fuel ASTM Properties and Elements

The ACES program fuel was provided by CRC through a commercial fuel supplier. It was an ultra-low sulfur diesel (ULSD) fuel that conformed to US EPA CFR Part 1065 ULSD fuel specifications. ASTM fuel properties are shown in Table 1. A sample was taken from the SwRI fuel tank where the ACES fuel was stored. The total aromatics content was 26.7 percent; the cetane number was 47.5; and the sulfur content was 4.50 ppm. Another sulfur analysis was performed on a fuel sample taken upstream of an engine fuel pump. The sulfur level was 5.20 ppm, which was comparable to that in the fuel tank, suggesting there was no sulfur contamination in the lines between the fuel tank and the engine fuel pump.

Table 2 shows the elements detected in the fuel. The most notable is the presence of residual lube oil elements such as calcium, phosphorus, and zinc. The presence of these elements was confirmed in two separate measurements. The sum of all measured elements' concentration in the fuel was about 9.5 ppm, with sulfur being the highest at 5.55 ppm, followed by phosphorus at 1.36 ppm, calcium at 1.38 ppm, zinc at 1.19 ppm, and lead at 6.28 ppb.

Mercury was not detected in the fuel.

TABLE 1. ASTM FUEL PROPERTIES

ASTM Test	Test Property / Description	Units	EM-6330-F Tank 37E
D86	Distillation		
	IBP	deg F	332
	10% Evaporated	deg F	420
	50% Evaporated	deg F	499
	90% Evaporated	deg F	585
	FBP	deg F	632
	Recovered	mL	97.6
	Residue	mL	1.5
	Loss	mL	0.9
D130	Copper Corrosion Strip	Rating	1A
D1319	Hydrocarbons by FIA		
	Aromatics	Vol %	26.7
	Olefins	Vol %	1.6
	Saturates	Vol %	71.7
D1796	Water & Sediment	mL	<0.02
D2500	Cloud Point	deg C	-24
D2622	Sulfur Content	wt %	<0.001
		ppm	<10
D5453	Sulfur Content	ppm	4.5
D4052	API Gravity at 60°F		33.8
	Specific Gravity at 60°F		0.8561
	Density at 15°C	grams/L	855.6
D445	Viscosity @ 40°C	cSt	2.613
D482	Ash Content	mass %	<0.001
D5291	Carbon Content	wt %	86.32
	Hydrogen Content	wt %	12.92
	Oxygen by Difference	wt %	0.76
D6079	Lubricity by HFRR		
	Major Axis	mm	0.38
	Minor Axis	mm	0.31
	Wear Scar Diameter	mm	0.345
	Wear Scar Description		evenly abraded oval
	Fuel Temperature	deg C	60
D613	Cetane Number		47.5
D93	Flash Point	deg F	149
	Flash Point	deg C	65
D976	Cetane Index (calculated)		44

TABLE 2. FUEL ELEMENTS

Element	Sample Result (mg/kg)	Reporting Limit[a] (mg/kg)	Method
Aluminum	<0.497	0.497	ICP
Antimony	<0.00198	0.00198	ICP/MS
Arsenic	<0.0494	0.0494	ICP/MS
Barium	<0.0794	0.0794	ICP
Beryllium	<0.00993	0.00993	ICP
Boron	<0.199	0.199	ICP
Cadmium	<0.00198	0.00198	ICP/MS
Calcium	1.38	0.497	ICP
Cerium	<0.000988	0.000988	ICP/MS
Chromium	<0.0497	0.0497	ICP
Cobalt	<0.000988	0.000988	ICP/MS
Copper	<0.0497	0.0497	ICP
Gallium	<0.000988	0.000988	ICP/MS
Gold	<0.00148	0.00148	ICP/MS
Indium	<0.000988	0.000988	ICP/MS
Iron	<0.497	0.497	ICP
Lanthanum	<0.000988	0.000988	ICP/MS
Lead	0.00628	0.00198	ICP/MS
Magnesium	<0.497	0.497	ICP
Manganese	<0.0497	0.0497	ICP
Molybdenum	<0.00494	0.00494	ICP/MS
Nickel	<0.00988	0.00988	ICP/MS
Palladium	0.00304	0.00198	ICP/MS
Phosphorus	1.36	0.199	ICP
Platinum	<0.000988	0.000988	ICP/MS
Potassium	<0.993	0.993	ICP
Rhodium	<0.000988	0.000988	ICP/MS
Rubidium	<0.000988	0.000988	ICP/MS
Selenium	0.00693	0.00494	ICP/MS
Silicon	<0.993	0.993	ICP
Silver	<0.00247	0.00247	ICP/MS
Sodium	<14.9	14.9	ICP
Strontium	0.00338	0.000988	ICP/MS
Sulfur	5.55	0.497	ICP
Thallium	<0.00198	0.00198	ICP/MS
Tin	0.00435	0.00198	ICP/MS
Titanium	<0.0497	0.0497	ICP
Tungsten	<0.00198	0.00198	ICP/MS
Uranium	<0.000988	0.000988	ICP/MS
Vanadium	<0.0497	0.0497	ICP
Yttrium	<0.0497	0.0497	ICP
Zinc	1.19	0.0497	ICP
Zirconium	<0.0497	0.0497	ICP

[a] Reporting limit is defined as 3 x the standard deviation of seven repeats of a NIST traceable concentration at the instrument minimum detection limit.

2.2.2 Lube Oil ASTM Analyses and Elemental Composition

Table 3 shows the ASTM analyses for the fresh lube oil, and for the used lube oil after 125 hours of degreening that was performed by the respective engine manufacturer. The dominant elements observed in the fresh lube oil were calcium (2268 ppm), phosphorus (1043 ppm), and zinc (1157 ppm). The used lube oil had higher levels of aluminum, barium, boron, copper, lead, magnesium, manganese, iron, and silicon, compared to the fresh oil, implying that these elements were accumulated in the oil during normal lubrication.

Mercury was not detected in the lube oil.

2.3 Sampling System

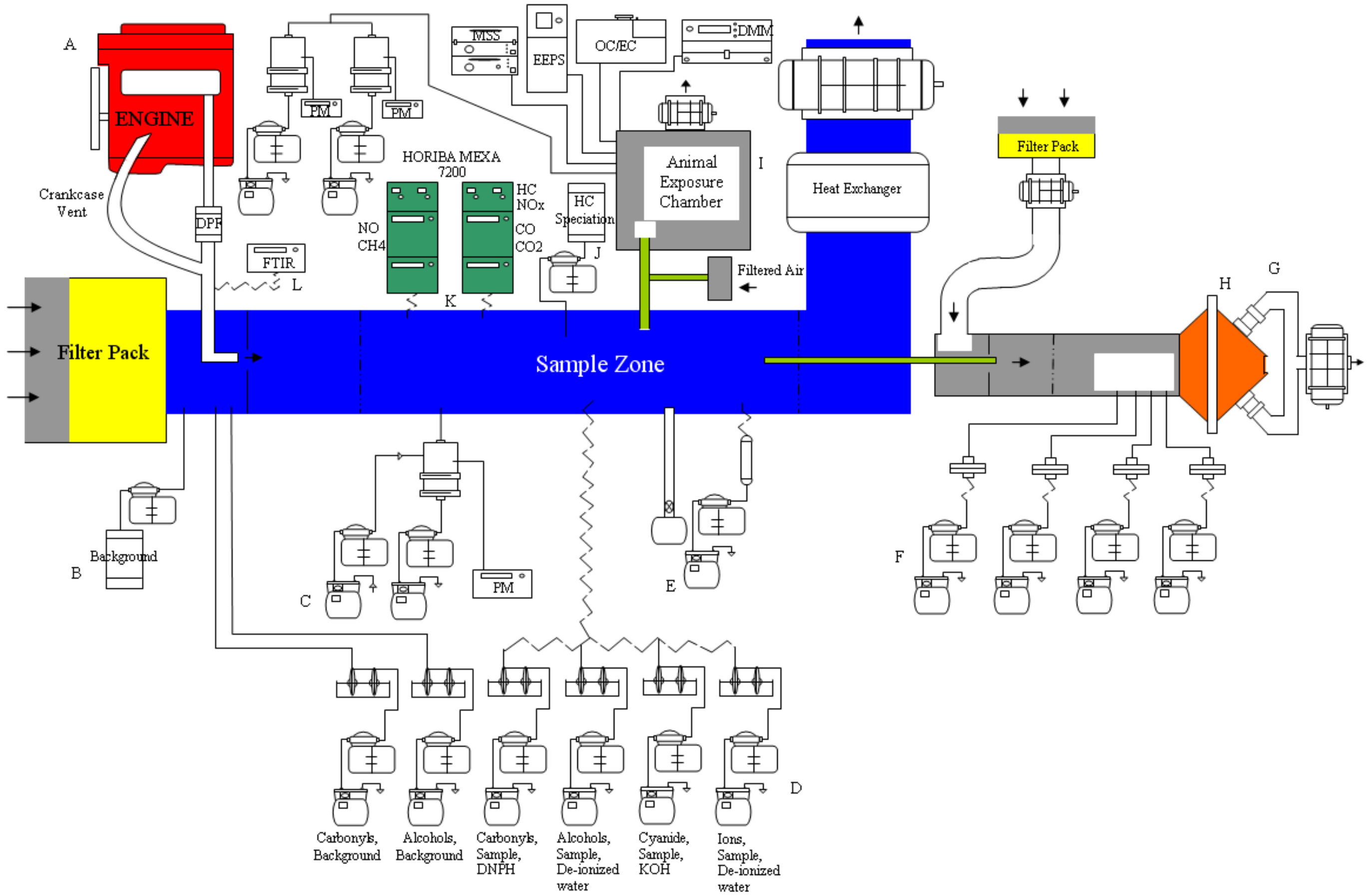
Figure 5 shows the overall sampling system of the experimental setup. Figure 6 shows a photograph of the exposure chamber along with the sample probes for the engine exhaust particle sizer (EEPS), Dekati Mass Monitor (DMM-230), micro-soot sensor (MSS), semi-continuous OC/EC, Teflo® filter sample train, and quartz filter sample train. The exposure chamber, provided by LRRI, was setup on the CVS tunnel. The nominal flow rate through the chamber was about 500 lpm. The 90 percent recovery residence time was on the order of four minutes, and the actual time to completely purge the chamber from any residuals was on the order of 20 minutes. Figure 7 shows the 8 x 10-inch Zefluor filter assembly followed by the four 4-inch XAD holders.

Referring to Figure 5, the dilution ratio between the constant volume sampler (CVS) tunnel and the exposure chamber was slightly less than 2:1, and the dilution ratio between the CVS tunnel and the 8 x 10 inch filter assembly was also about 2:1. The average dilution ratio between engine exhaust and CVS was about 20:1. Dilution ratio (DR) is defined as:

DR = (dilution air flow + sample flow)/(sample flow)

TABLE 3. LUBE OIL PROPERTIES FOR FRESH OIL AND AFTER 125 HOURS OF ENGINE AND DPF DEGREENING BY THE ENGINE MANUFACTURER

ASTM Test	Test Property / Description	Units	EM-3275-EO Fresh Lube Oil	EM-3276-EO Used Oil Engine A	EM-3278-EO Used Oil Engine B	EM-3277-EO Used Oil Engine C	EM-3282-EO Used Oil Engine D
D3524M	Fuel Dilution, Diesel	wt %	<0.3	<0.3	<0.3	1.2	<0.3
D4291	Glycol	ppm	<100	<100	<100	<100	<100
D445	Viscosity @ 100 °C	cSt	15.19	13.83	14.47	13.23	20.64
D445	Viscosity @ 40 °C	cSt	113.86	102.2	112.09	96.28	78.94
D4739	Total Base Number						
	Inflection	mg KOH/g	7.63	5.61	6.16	6.11	7.5
	Buffer	mg KOH/g	7.47	4.13	4.78	4.48	6.17
D5185	Element Analysis						
	Aluminum	ppm	2	3	2	2	2
	Antimony	ppm	<1	<1	<1	<1	<1
	Barium	ppm	<1	3	3	<1	<1
	Boron	ppm	<1	6	8	2	3
	Calcium	ppm	2268	2459	1879	2291	2350
	Chromium	ppm	<1	6	3	<1	2
	Copper	ppm	<1	12	13	8	96
	Iron	ppm	1	61	72	16	26
	Lead	ppm	<1	4	5	1	6
	Magnesium	ppm	5	8	261	32	125
	Manganese	ppm	<1	5	4	1	1
	Molybdenum	ppm	<1	9	<1	2	<1
	Nickel	ppm	<1	<1	<1	4	25
	Phosphorus	ppm	1043	978	1010	984	1125
	Silicon	ppm	3	36	36	23	68
	Silver	ppm	<1	<1	<1	<1	2
	Sodium	ppm	<5	10	8	6	7
	Tin	ppm	<1	4	4	1	4
	Zinc	ppm	1157	1209	1186	1133	1269
	Potassium	ppm	<5	<5	6	<5	<5
	Strontium	ppm	<1	<1	<1	<1	<1
	Vanadium	ppm	<1	<1	<1	<1	<1
	Titanium	ppm	<1	<1	<1	<1	<1
	Cadmium	ppm	<1	<1	<1	<1	<1
D664	Total Acid Number						
	Inflection	mg KOH/g	N/A	N/A	N/A	N/A	N/A
	Buffer	mg KOH/g	1.75	2.39	1.95	1.81	1.76
E168	FTIR (Oxidation & Nitration)						
	Diff. @ 5.8um	ABS/cm	0	2.86	0.18	2.14	0.37
	Diff. @ 6.1um	ABS/cm	0	0.28	0.18	0.09	0.09
TGA Soot	Residue	wt %	0.8	0.9	0.6	0.9	0.8
	Volatiles	wt %	99	98	97.1	98.8	98.9
	Soot	wt %	0.142	1.039	2.274	0.358	0.33



A 2007 Heavy-Duty Diesel Engine with DPF
B Background bag sample of dilution air for CO, CO_2, NO_X, NO, THC, CH_4, and C_2-C_{12} speciation
C Regulated PM following CFR Part 1065 using 47 mm Teflo filter
D Impingers for carbonyls, alcohols, ions, and cyanide ion
E Sorbent traps for nitrosamines and Summa canister for SVOC
F Auxiliary PM samples on 47mm filters for inorganic ions (Fluoropore Filter), XRF (Teflo Filter), and ICP-MS (Fluoropore Filter), DCI/GC (TX-40 filter)
G XAD traps for gas phase semi-volatile compounds: PAH, oxyPAH, nitroPAH, hopanes, steranes, carpanes, polar organics, high molecular weight alkanes and cycloalkanes, dioxins, furans
H Filter (8x10 inch Zefluor) for particulate-phase semi-volatile compounds: PAH, oxyPAH, nitroPAH, dioxins, furans, hopanes, steranes, carpanes, polar organics, high molecular weight alkanes and cycloalkanes, dioxins, furans
I Animal Exposure chamber (no animals present) PM mass using Teflo filter, size and number using EEPS, real time total PM using DMM-230, real-time soot using MSS, OC/EC collection using a pair of quartz filters, and semi-continuous OC/EC (very limited use)
J Proportional bag sample for hydrocarbon speciation of C_2 through C_{12} compounds
K Horiba MEXA 7200 for THC, CO, CO_2, NO_X , NO analyzer, and CH_4 analyzer
L FTIR for nitrogen compounds

FIGURE 5. OVERALL SAMPLING SYSTEM

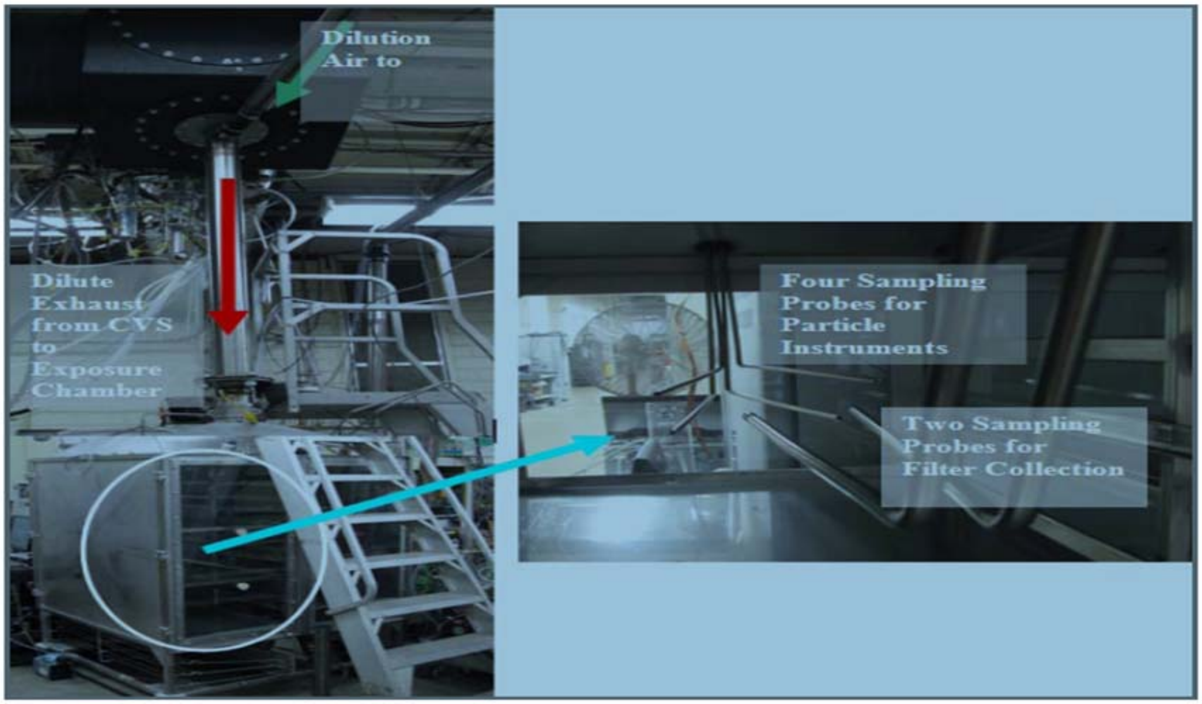


FIGURE 6. EXPOSURE CHAMBER

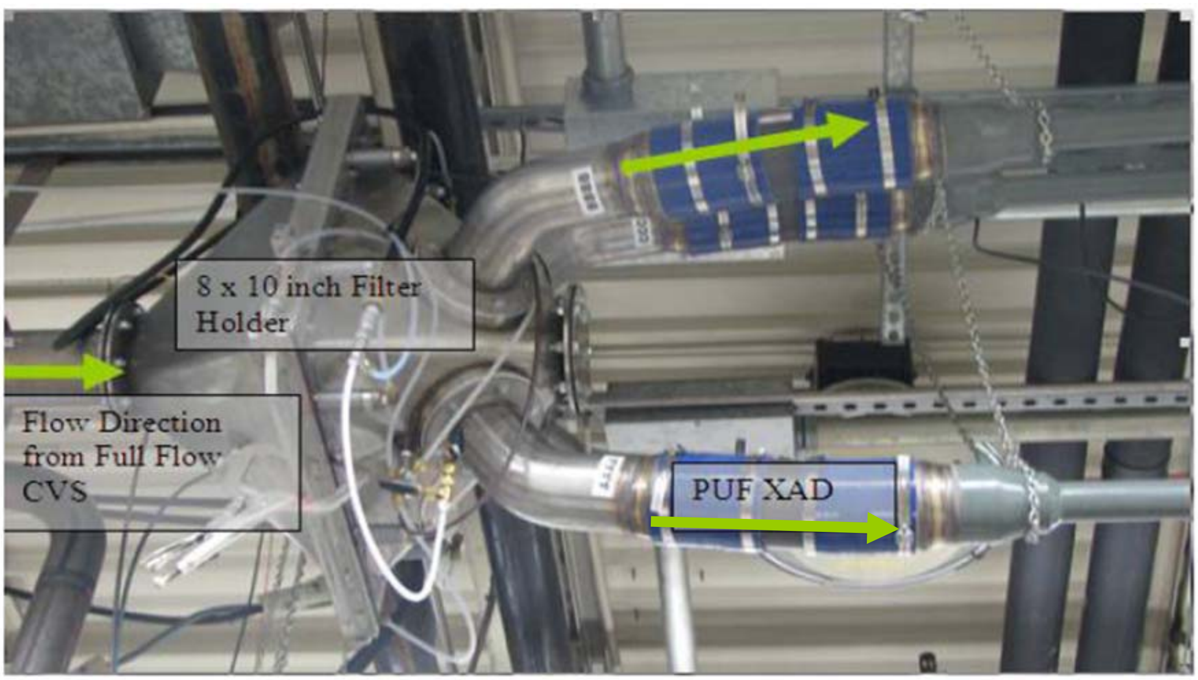


FIGURE 7. ZEFLUOR FILTER (8 X 10-INCH) AND XAD ASSEMBLY

3.0 TEST MATRIX

Table 4 shows the series of tests performed for each of the four candidate ACES engines. For the backup engine, the test included only regulated emissions using Modes 1, 3, and 5, and the hot-start FTP with and without blow-by at SwRI's San Antonio elevation, and at LRRI's, Albuquerque simulated elevation. Table 5 shows the detailed test matrix for each engine in the order it was tested, along with the length of each test cycle.

Table 6 shows the measurements done for each test performed on each engine. Figures 8 through 11 show the percent normalized torque and speed profiles for the different cycles used in ACES Phase 1. Normalized engine torque is defined as the actual torque over the maximum torque produced by the engine. Normalized engine speed is defined as (actual speed –warm-idle speed)/(rated power speed – warm-idle). Thus it is possible for the normalized speed to be over 100 percent, if the actual engine speed is higher than the rated speed.

TABLE 4. NUMBER OF REGULATED AND UNREGULATED EMISSIONS TESTS FOR EACH ENGINE

Cycle	Regulated Pollutants	Unregulated
Hot-Start FTP	3	[a,h]
Mode 1, rated speed, 100% load	3	[a,h]
Mode 3, rated speed, 50% load	3	[a,h]
Mode 5, peak torque speed, 100% load	3	[a,h]
Cold-Start FTP	1	[a,h]
Hot-Start FTP	6 [b]	6 [b]
Composite CARB HHDDE Cycle Mode 1, 2, and 5 (creep, transient, and idle), CARBX-ICT	2	2
Composite CARB HHDDE Cycle Mode 3 and 4 (cruise and high-speed cruise), CARBZ-CH	2	2
16-Hour Transient Cycle	3	3
Tunnel Blanks [c,d]	4 for Engine A and 3 for others	4 for Engine A and 3 for others
Tunnel Background [e,f]		1
Dioxins and Furans [g]		1

[a] Only real time particle size, number, total mass, and solid mass were performed for these tests.
[b] Three hot-start FTP runs with blow-by and three without blow-by.
[c] Tunnel blank is a 20-minute test run exactly like an engine test, except the engine is off.
[d] One tunnel blank after cleaning CVS tunnel but before running the Engine. A second tunnel blank after finishing the six hot-start FTP runs, which is also before starting the CARB composite modes. A third tunnel blank after finishing the CARB composite modes but before the 16-Hour transient cycle. A fourth tunnel blank after finishing the 16-Hour transient cycle.
[e] Tunnel background is a 16-Hour test where samples are taken from the dilution air immediately downstream of the CVS HEPA filter.
[f] Tunnel background dilution air was collected for 16 hours using 8 x 10 Zefluor filter followed by four XAD traps.
[g] Dioxins and furans were collected separately for 16 hours on Engines A, C, and D using 8 x 10 Zefluor filters followed by four XAD traps.
h Data were shared with each engine manufacturer to make sure that the engine emissions performance complied with the manufacturer's expectation and to get approval to proceed with the program.

TABLE 5. DETAILED TEST MATRIX FOR EACH ACES ENGINE

Test	Regulated Pollutants (No. of Runs)	Unregulated (No. of Runs)	Cycle Length
Tunnel Blank No. 1	1	1	20 minutes
Hot-Start FTP	3	[a]	20 minutes
Mode 1	3	[a]	20 minutes
Mode 3	3	[a]	20 minutes
Mode 5	3	[a]	20 minutes
Cold-Start FTP	1	[a]	20 minutes
Hot-Start FTP	6 [b]	6 [b]	20 minutes
Tunnel Blank No. 2	1	1	20 minutes
Composite CARB HHDDE Cycle Modes 1, 2, and 5 (idle, creep, transient), CARBx-ICT	2	2	39 minutes
Composite CARB HHDDE Cycle Modes 3 and 4 (cruise and high-speed cruise), CARBz-CH	2	2	48 minutes
Tunnel Blank No. 3	1	1	20 minutes
16-Hour Transient Cycle [c] (Three Repeats)	1 1 1	1 1 1	16 hours 16 hours 16 hours
Tunnel Blank No. 4	1	1	20 minutes
Tunnel Background No. 1	N/A	1	16 hours
Dioxins/Furans [d]			16 hours

[a] Only real time particle size, number, total mass, solid mass, and semi-continuous OC was performed for these modes.
[b] Three hot-start FTP runs with blow-by and three without blow-by.
[c] Each 16-Hour cycle (four runs of 4-hour segments), ran over a two-day period, at 8 hours per day.
[d] Dioxins/furans collection was performed on Engines A, C, and D only, along with a separate tunnel background for each run.

TABLE 6. SAMPLING/ANALYSIS MATRIX FOR REGULATED AND UNREGULATED EMISSIONS ON EACH ACES ENGINE

Parameter; Analytical Method(s)	Media	FTP Hot Start-W/O Blowby	FTP Hot Start-W Blowby	CARBx-ICT	CARBz-CH	16-Hr Transient Cycle	Tunnel Blank	16-Hr Tunnel Background	Background Corrected[a]?
Total Hydrocarbon (THC)	FID	3	3	2	2	3	3	0	Yes
Oxides of Nitrogen (NO_X)	Chemi-luminescent	3	3	2	2	3	3	0	Yes
Carbon Monoxide (CO)	NDIR	3	3	2	2	3	3	0	Yes
Particulate Matter (PM)	47 mm Teflon® membrane filter	3	3	2	2	3	3	0	No
NO2	Chemi-luminescent	3	3	2	2	3	3	0	Yes
N_2O	FTIR	3	3	2	2	3	3	0	No
OC/EC	Quartz filter	3	3	2	2	3	3	0	No
Particle Size and Number	EEPS	3	3	2	2	3	3	0	No
Real Time PM	DMM-230	3	3	2	2	3	3	0	No
Metals, elements; ICP/MS	Fluoropore® filter + DI Water Impinger	3	3	2	2	3	3	0	No
Ca, P, S, K, Fe, Si, Na; EDXRF	Fluoropore® filter	3	3	2	2	3	3	0	No
Inorganic ions and acids; IC	Fluoropore® filter + DI Water Impinger	3	3	2	2	3	3	0	No
pH, H+; pH, Titration	DI Water Impinger	3	3	2	2	3	3	0	No
Cyanide, Cr(VI) ; GC-ECD, ICP/MS	KOH Impinger	3	3	2	2	3	3	0	No
SO_2; IC	H_2O_2 Impinger	3	3	2	2	3	3	0	No
Gas phase hydrocarbons (C2–C12a;GC-FID	Tedlar® Bag	3	3	2	2	3	3	0	Yes
Carbonyl compounds; HPLC-UV	DNPH Impinger	3	3	2	2	3	3	0	Yes
Alcohols; GC-FID	DI Water Impinger	3	3	2	2	3	3	0	Yes
Dioxins and Furans; HRGC/HRMS	Zefluor® Filter + XAD® Cartridge	0	0	0	0	1	0	1	Yes
Selected VOCs; GC/MS	SUMMA® Canister	3	3	2	2	1	3	0	No
PAH; GC/MS	Zefluor® Filter + XAD® Cartridge	3	3	2	2	3	3	1	No
nitroPAH; GC/MS		3	3	2	2	1	3	1	No
Hopane/Steranes/Carpanes; GC/MS		3	3	2	2	3	3	0	No
Alkanes, Alkenes, Alkynes, Cyclo- and branched (C14-C40); GC/MS		3	3	2	2	1	3	0	No
Polar compounds, Oxygenated PAH, Organic Acids; GC/MS		3	3	2	2	1	3	1	No
Nitrosamines; GC/MS	Thermosorb®	3	3	2	2	1	3	0	No

[a] Background corrected means that a sample of the background dilution air taken from downstream of the HEPA filter in the CVS tunnel is analyzed for the same species concentration measured in the dilute exhaust, and then subtracted from the dilute exhaust species concentration using the following equation: Xbgc=Xm –(1-1/DR)*Xbg, where Xbgc is the corrected concentration, Xm is the measured concentration, and Xbg is the background concentration of the species of interest.

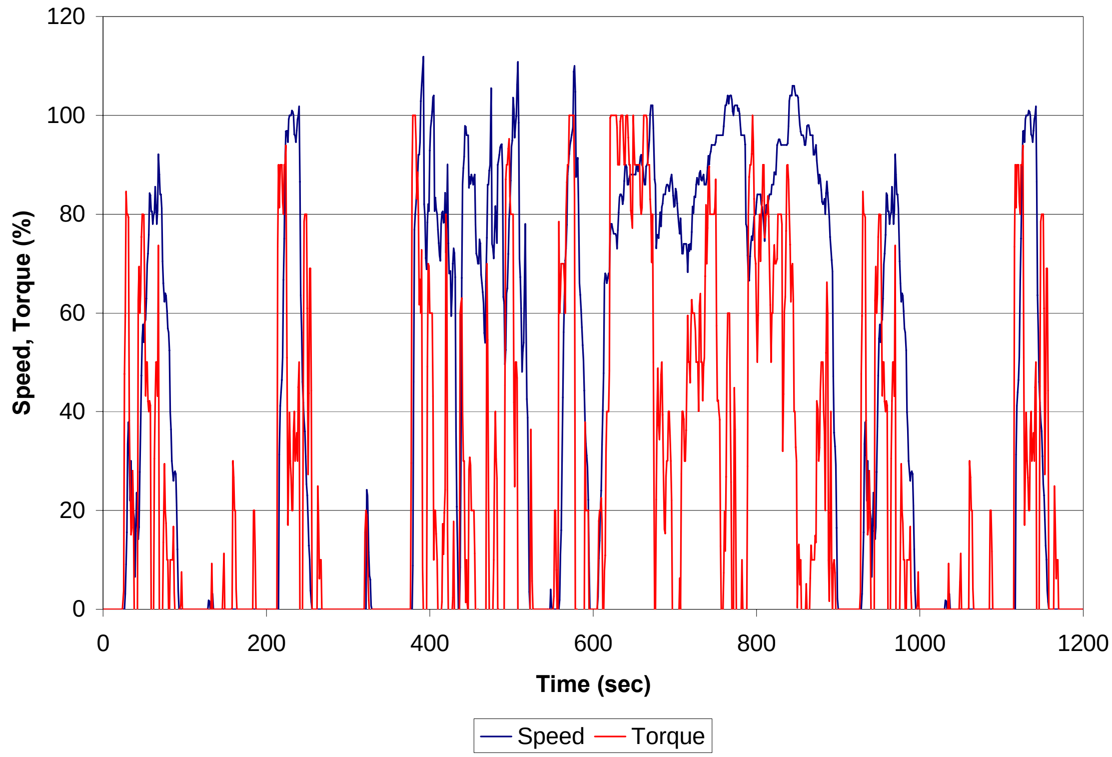


FIGURE 8. FTP TRANSIENT CYCLE NORMALIZED TORQUE AND SPEED PROFILES

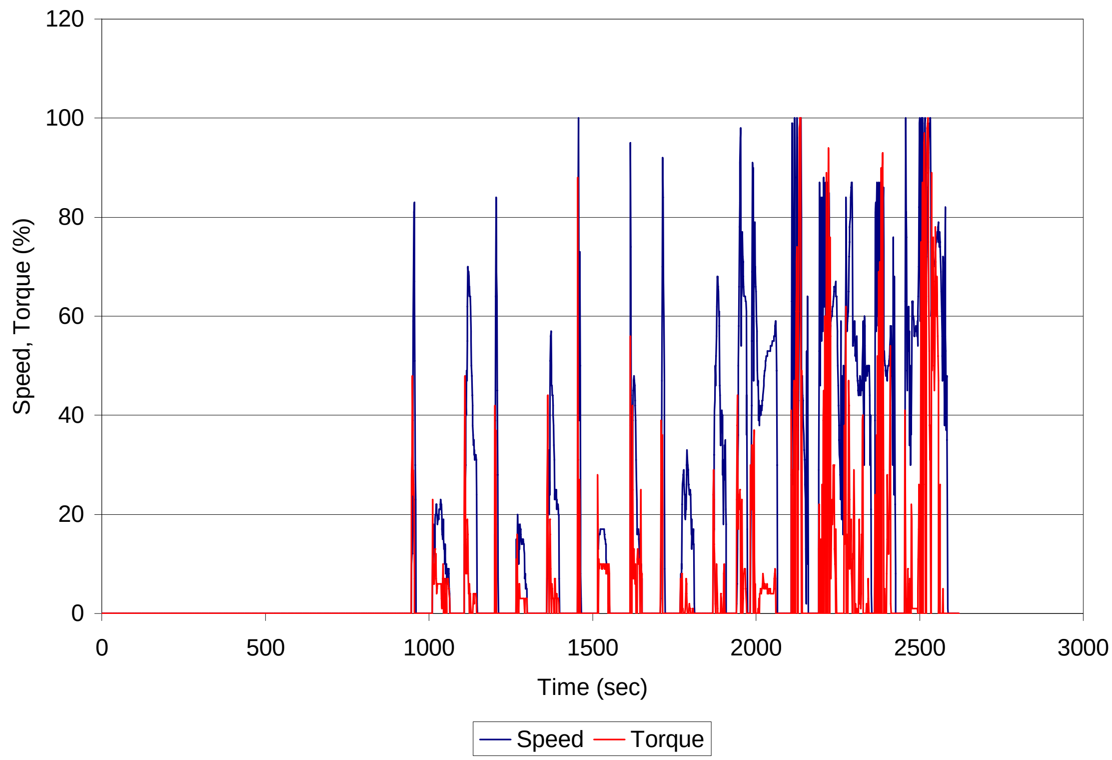


FIGURE 9. CARBX-ICT CYCLE NORMALIZED TORQUE AND SPEED PROFILES

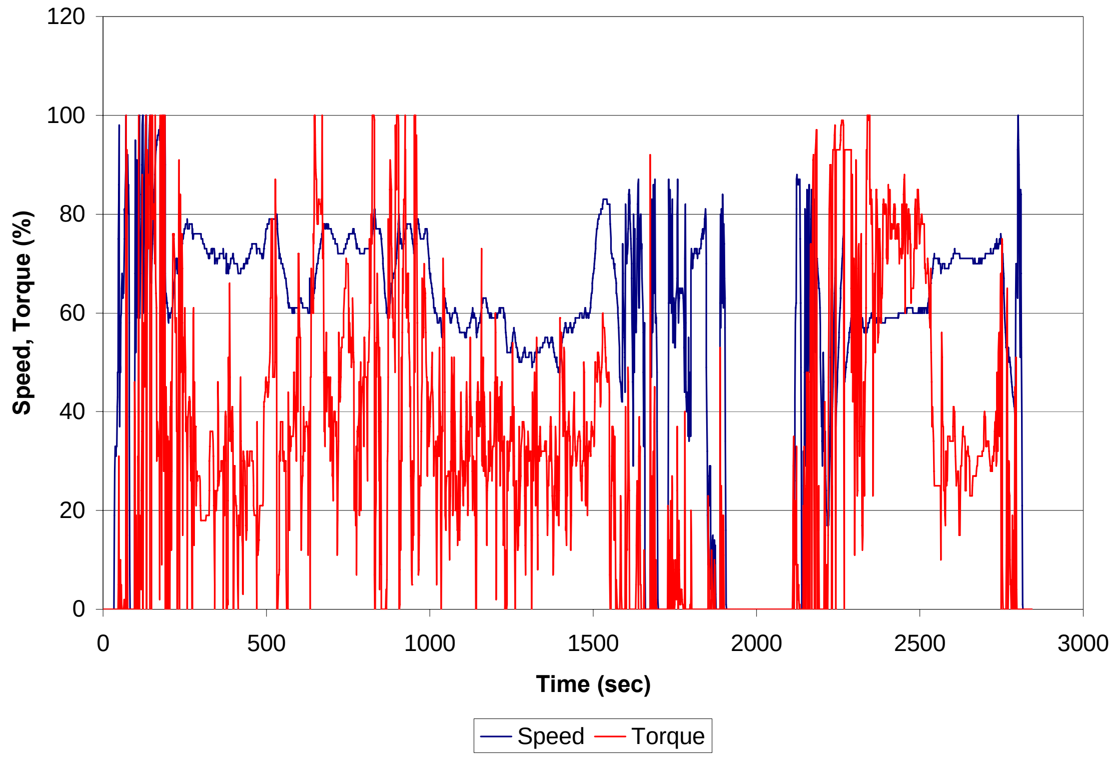


FIGURE 10. CARBZ-CH CYCLE NORMALIZED TORQUE AND SPEED PROFILES

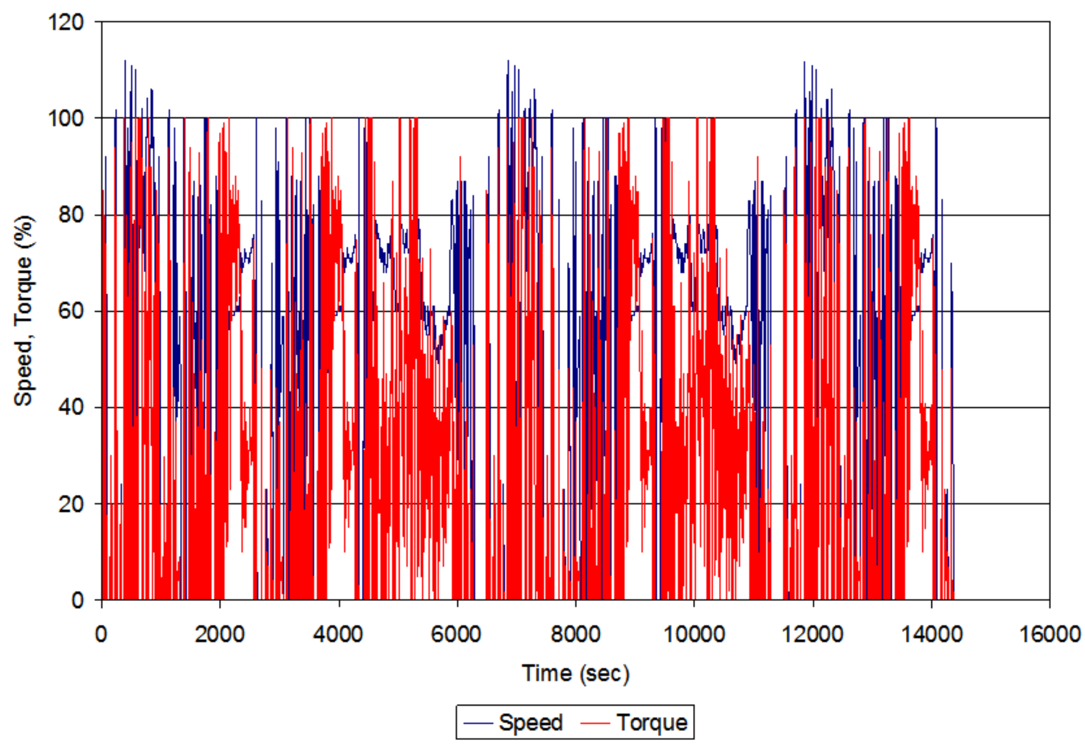


FIGURE 11. FOUR-HOUR REPEATED SEGMENT OF THE NORMALIZED TORQUE AND SPEED PROFILES FOR THE 16-HOUR CYCLE

4.0 PROCEDURES

Tasks performed prior to and during engine testing are described in this section.

4.1 Full Flow Constant Volume Sampler Tunnel Cleanup and Conditioning

In Project E-66, it was learned that the PM emissions reported using tunnel blank filter collection without engine operation is similar to that reported using a diesel engine equipped with a DPF. It is also known from previous work and from Project E-66 [4] that the history of operation of the full flow CVS using different technology engines affects the time required for unregulated and PM emission measurement stabilization. For example, during Project E-66, it took a total of 10 hours of continuous engine operation at rated power to stabilize PM emissions. Therefore, prior to test cell engine installation for the ACES project, a thorough full flow CVS tunnel cleaning was performed. Due to the very low PM and unregulated emission levels expected from the 2007 engines, it was important to clean the internal surface of the tunnel to remove any adsorbed material that could interfere with PM and unregulated emissions measurements. Volatile and semi-volatile materials that may have adsorbed onto the internal surface of the tunnel or the surface soot layer could desorb during an engine run or when sampling a tunnel blank. The tunnel was completely removed from the test cell and cleaned using a small amount of Simple Green detergent and power washed and rinsed using water. Figures 12 and 13 shows the CVS sample zone before and after cleaning.

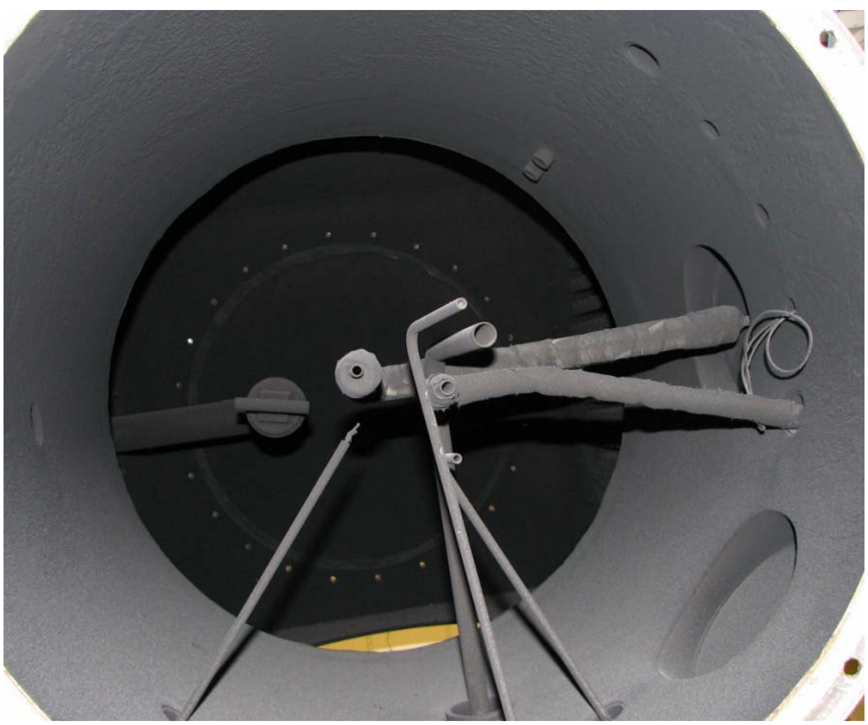


FIGURE 12. CVS SAMPLE ZONE BEFORE CLEANING

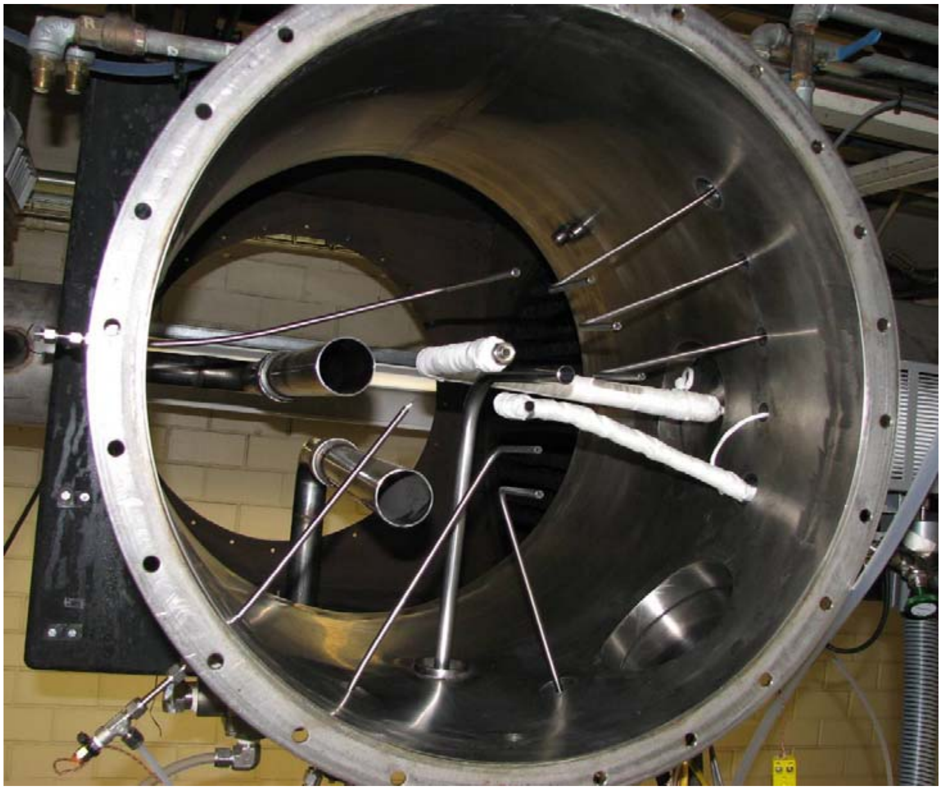


FIGURE 13. CVS SAMPLE ZONE AFTER CLEANING

After the tunnel was cleaned, reassembled, and verified via propane recovery checks, the first 2007 engine, Engine A, was installed in the test cell with new stainless steel exhaust piping to the CVS. The length of the exhaust pipe between the DPF exit and the CVS inlet was on the order of 12 feet. This section was heated or insulated. Next, the engine was power validated to make sure it performed as expected by the manufacturer. Engine and sampling system conditioning was then performed by running the engine at rated power while operating the sampling systems for a period of 10 hours. The test sequence for subsequent engines did not include tunnel cleaning, but did include tunnel conditioning, similar to the first engine.

4.2 Regulated Emissions Measurements

Regulated emissions including NO_x, CO, and NMHC were measured in accordance with CFR Part 1065 using a Horiba MEXA-7000 series emission bench. NO_x was measured using the chemiluminescent detection method. CO was measured using the non-dispersive infrared detection method, and NMHC was determined by taking the difference between THC and methane measurements using the flame ionization detection method.

Regulated PM was measured using a single Teflon® membrane (Pall Teflo®) filter, 47 mm in diameter that was maintained at $47^oC \pm 5°C$ in accordance with CFR Part 1065. The filter face velocity was maintained close to 100 cm/sec. The filter room used for filter conditioning and weighing was maintained in accordance with CFR Part 1065 requirements. The filter weighing procedure included three filter pre and three filter post weights. The averages of the pre and post weights were used to determine the filter weight gain. In Project E-66, SwRI demonstrated a filter weighing variability of less than ±2.5 μg (one standard deviation) using Teflon® membrane filters.

4.3 Sampling and Analysis of Unregulated Emissions

Analysis of unregulated emissions was performed at SwRI and at DRI. A summary of analytical responsibilities and notes on methodology are presented in Table 7.

SwRI determined ions by ion chromatography, metals and other elements by inductively coupled plasma/mass spectroscopy (ICP/MS) and cold vapor atomic absorption spectroscopy (CVAAS); and selected air pollutants by gas chromatography/mass spectroscopy (GC/MS). Speciation of C_1 through C_{12} hydrocarbons including alcohols, aldehydes, and ketones was performed using GC and high performance liquid chromatography (HPLC). Fourier transform infrared spectroscopy (FTIR) was used primarily for continuous monitoring of N_2O. SwRI utilized dual chemiluminescent NO_x detectors, one operating in NO mode and one in NO_x mode, so an accurate determination of NO_2 could be made as the difference between NO_x and NO. Cyanide samples were collected in impingers and analyzed by GC-ECD. Dioxins and furans samples were collected on an 8 by 10-inch filter followed by four XAD traps, and were analyzed in accordance with EPA Method 8290 using high resolution gas chromatography (HRGC) and high resolution mass spectroscopy (HRMS).

For the animal exposure chamber, real-time particle size distribution was measured using the TSI engine exhaust particle sizer (EEPS); real time PM mass was measured with the Dekati DMM-230; real time soot mass was measured by the AVL micro-soot sensor (MSS); and organic carbon was measured using the Sunset Laboratories OC/EC instrument with Zefluor® filters. During engine and CVS conditioning and stabilization, OC/EC quartz filters were also used with the animal exposure chamber using a primary and a backup 47 mm quartz filter. The quartz filters were then analyzed for OC/EC by DRI.

DRI provided analyses for hopanes, steranes, polar compounds, heavy alkanes ($>C_{12}$), polycyclic aromatic hydrocarbons (PAH), nitroPAH, oxyPAH, and organic acids. DRI also provided analyses for OC/EC and nitrosamines, as well as a subset of metals and elements that were analyzed by energy dispersive X-ray fluorescence (EDXRF) spectroscopy.

4.3.1 Filter and XAD Sample Collection for Chemical Analysis

For the collection of filter and XAD® samples for chemical analysis, SwRI used a large supplemental secondary dilution tunnel that permitted the use of an 8 by 10-inch (203 by 254 mm) Zefluor® filter followed by four 4-inch diameter XAD® cartridges that were sampling in parallel, downstream of the filter. The nominal flow rate through the filter and four XAD® cartridges was about 1700 slpm.

TABLE 7. SUMMARY OF ANALYSIS METHODOLOGY AND RESPONSIBILITY

Analyte Class	Notes	Method	Laboratory
Metals and Elements	47 mm Teflo® filter, 28 slpm	ICP/MS, ICP	SwRI
Ions	Water Impinger (4 slpm), 47 mm TX-40 filter (28 slpm)	IC	SwRI
Fuel/Oil PM Contribution	47 mm TX-40 filter, selected samples only, 28 slpm	DFI/GC	SwRI
Hydrogen Ion	H^+, water impinger, 4 slpm	Titration	SwRI
Cyanide Ion	Impinger, 4 slpm	GC/ECD	SwRI
VOC (C_1 – C_{12})	Tedlar ® bag	GC/FID	SwRI
Carbonyl compounds	DNPH impingers, 4 slpm	HPLC	SwRI
Alcohols	DI water impinger, 4 slpm	GC/FID	SwRI
Selected VOCs	Solid sorbent, 1 slpm (nitromethane, nitropropane, hydrogen sulfide, carbonyl sulfide)	GC/MS	SwRI
Dioxins/Furans	One sample per engine, on 16-hr integrated sample, gas- and particle-phase extracts analyzed together, 1700 slpm	GC/MS	SwRI
Real Time Total PM	1Hz, 10 slpm	DMM-230	SwRI
Real Time Soot	1Hz, 2 slpm	MSS	SwRI
Real Time PM Size and Number	1Hz, 10 slpm	EEPS	SwRI
Metals and Elements	47 mm Teflo® filter, 28 slpm	EDXRF	DRI
PAH	Gas- and particle-phase extracts analyzed together, except 16-Hour integrated sample, 1700 slpm	GC/MS	DRI
NitroPAH	Gas- and particle-phase extracts analyzed together, except 16-Hour integrated sample, 1700 slpm	GC/MS	DRI
Hopanes, Steranes	Gas- and particle-phase extracts analyzed together, except 16-Hour integrated sample, 1700 slpm	GC/MS	DRI
Polar compounds	Gas- and particle-phase extracts analyzed together, except 16-Hour integrated sample, 1700 slpm	GC/MS	DRI
Other SVOC (C_{14}-C_{40})	Gas- and particle-phase extracts analyzed together, except 16-Hour integrated sample, 1700 slpm	GC/MS	DRI
Nitrosamines	Thermosorb N®, 1 slpm	GC/MS	DRI
OC/EC	Quartz filters, 58 slpm	TOR and TOT	DRI

The breakthrough volume of semi-volatile and volatile components for XAD® adsorbent is not known. However, XAD® resins are known to have much higher collection efficiency for naphthalene and other volatile PAH than polyurethane foam (PUF) alone.[5, 6] Experiments performed at the University of California, Los Angeles with three layers of XAD®, 10 g each, showed that the first layer collected 93-97 percent of naphthalene and other semi-volatile PAH, such as fluoranthene and pyrene (24-hrs sampling, 113 LPM). Thus, 20 g of XAD® should be sufficient to collect most of the compounds of interest. However, to check the validity of this approach, primary and backup XAD® cartridges were used and extracted separately, and all primary and backup XAD® cartridges were analyzed for breakthrough for the 16-Hour cycle. For the rest of the cycles, backup XAD® cartridges were analyzed for three FTP runs performed on the first engine tested, Engine A. The remainder of the extracts for the rest of cycles and engines were saved by DRI, but not analyzed.

4.3.2 Ions and Inorganic Acids

Samples were collected in impingers containing a potassium hydroxide solution and analyzed for cyanide ion via GC-ECD (Electron Capture Detector). The GC-ECD procedure for cyanide analysis was developed at SwRI and published in EPA document 600-2-80-068, "Analytical Procedures for Characterizing Unregulated Emissions from Vehicles Using Middle-Distillate Fuels," 1980.

Hexavalent chromium Cr(VI) was collected using a modified EPA Method 061 and analyzed by EPA 7199. Similar to cyanide, an impinger filled with a potassium hydroxide solution was used to collect the Cr(VI), and the impinger solution was subsequently analyzed by ion chromatography.

Anions and cations (NH_4^+, NO_2^-, NO_3^-, SO_4^{2-}), and inorganic acids (HNO_2, HNO_3, H_2SO_4) samples were collected on Teflon membrane filters, and by water impingers. Filters were extracted to remove the analytes of interest, and the extract was analyzed using ion chromatography (IC). Impinger solutions were analyzed by IC as well; however, it was not possible to differentiate between anions and cations from ionic species versus inorganic acids. In addition, it should be noted that NO_2 passing through water may form HNO_2 and HNO_3. A titration to determine the H^+ concentration was performed, and the pH was measured.

4.3.3 Metals and Elements

Filter samples were analyzed with ICP/MS and EDXRF to ensure that analyses for all required elements were covered with adequate detection limits. Total Br, Cl, S, K, Na, P, Ca, Fe, and Si were determined by energy dispersive x-ray fluorescence (EDXRF).

The particulate filters for ICP/MS metals analysis were digested with high purity acids. The majority of the metals were analyzed via ICP/MS using EPA SW-846 Method 6020 to get the lowest possible detection limits. The ICP/MS method has been used for analysis of motor vehicle samples by several investigators [7]. Blank filters were analyzed to assess any contribution from the media and the extraction/digestion solutions.

The ICP/MS instrument is standardized using NIST traceable standard reference materials. Prior to analyzing any samples, the standardization is verified with a second NIST traceable reference material. This second standard is from a different lot or manufacturer than the first standardization material. Immediately after the second standard is run, a blank is run to verify the zero setting. The second standard is required to be within 90-110 percent recovery of the certified value. The absolute value of the check blank is required to be below the reporting limit for the analyte. If either condition has not been met, the analysis would be terminated and the instrument re-standardized and re-checked. The standard and check blank are re-run after every 10 samples, and at the end of the run to ensure that the instrument remains in control throughout the entire run. If a standard falls out of the control limits, the analysis is terminated, the instrument re-standardized, and all samples since the last compliant standard are re-run. As an internal check, duplicate analyses are performed on approximately ten percent of samples, selected at random.

Tunnel blank samples were collected for each analyte as designated in Table 6.

4.3.4 Selected Volatile Organic Compounds

Samples for the selected volatile organic compounds (nitromethane, nitropropane, hydrogen sulfide, carbonyl sulfide), were collected in sample bags and sorbent traps specific to the analytes. They were analyzed by GC/MS. SwRI Test and Analysis Procedures TAP 0404014 and 0404015 were utilized. TAP 0404014 is based upon EPA method TO-15, which uses a combination of multi-sorbent tubes and cryogenic focusing for sample concentration with subsequent analysis by GC/MS. TAP 0404015 is based upon SW-846 Method 5040 and covers the determination of volatile organic compounds (VOCs), collected on Tenax® and Tenax®/charcoal sorbent cartridges using a volatile organic sampling train (VOST). This method was utilized in conjunction with an appropriate analytical method, SW-846 8240, Volatile Analysis by GC/MS. Because a majority of gas streams sampled using VOST will contain a high concentration of water, the analytical method is based on the quantitative thermal desorption of volatile compounds from the Tenax® and Tenax®/charcoal traps with analysis by purge and trap GC/MS. The contents of the sorbent cartridges are spiked with an internal standard/surrogate solution and thermally desorbed with organic free nitrogen or helium, bubbled through organic-free water and trapped on an analytical absorbent trap. After the purge, the analytical trap is dry purged for two additional minutes, then heated rapidly to 240°C, with the carrier flow reversed so the effluent flow from the analytical trap is directed to the GC/MS. The VOCs are separated by temperature-programmed gas chromatography and detected by low-resolution mass spectrometry. The concentrations of VOCs are calculated using the internal standard technique. Tunnel blank samples were collected for each analyte as specified in Table 6.

4.3.5 Hydrocarbon Speciation of C_2 Through C_{12} Compounds

Vapor phase C_2 to C_{12} hydrocarbon species were sampled with Tedlar® bags from the primary dilution tunnel. Analysis of these samples was conducted within five to 10 minutes after collection to avoid degradation of the more reactive species, such as 1,3-butadiene. Carbonyls and alcohols were sampled from the primary dilution tunnel via impingers. Alcohols were collected in impingers filled with deionized water, and carbonyls with a solution of dinitrophenylhydrazine (DNPH) in acetonitrile. To minimize degradation, aldehyde samples were analyzed as soon as the sampling was completed.

The analytical procedures used for conducting hydrocarbon speciation (C_2 to C_{12} hydrocarbons, aldehydes and ketones, and alcohols) are similar to the CRC Auto/Oil Phase II protocols. With these methods, exhaust emissions samples are analyzed for the presence of more than 200 different exhaust species. Four GC procedures and one HPLC procedure are used to identify and quantify compounds. A brief description of these procedures is given below.

The first GC procedure uses a 15 m x 0.53 mm I.D. DB-WAX (1µm film) pre-column and a 50 m x 0.53 mm I.D. (10 femtometer film) Alumina PLOT/KCI (Carbopack®) column to permit the separation and determination of exhaust concentrations of C_1-C_4 individual hydrocarbon species, including ethane, ethylene, acetylene, propane, propylene, propadiene, butane, trans-2-butene, 1-butyne, and cis-2-butene. Bag samples were analyzed using a gas chromatograph equipped with a flame ionization detector (FID). The gas chromatograph system utilizes two analytical columns. The carrier gas is helium. An external multiple component standard in zero air is used to quantify the results. Detection limits for the procedure are on the order of 5 ppbC in dilute exhaust for all compounds.

The second GC procedure uses a 60 m x 0.32 mm I.D. (10 µm film) DB-1 column to provide separation and exhaust concentrations for more than 100 C_5-C_{12} individual HC compounds. Bag samples are analyzed using a gas chromatograph equipped with a flame ionization detector (FID). The GC system utilizes a FID, a pneumatically operated and electrically controlled valve, and an analytical column. The carrier gas is helium. An external multiple component standard in zero air is used to quantify the results. Detection limits for the procedure are on the order of 10 ppbC in dilute exhaust for all compounds.

The third GC procedure uses a separate system configured similarly to the second GC method to determine individual concentrations of benzene and toluene according to CRC Auto/Oil Phase II Protocols. The third GC utilizes a 30 m x 0.25 mm I.D. (0.25 µm film) DB-5 column instead of a DB-1 column.

An HPLC with a Zorbax® octadecasilane (ODS) column was utilized for the analysis of aldehydes and ketones. Samples were collected in impingers with a solution of DNPH in acetonitrile. For analysis, a portion of the acetonitrile solution was injected into a liquid chromatograph equipped with an ultraviolet (UV) detector. External standards of the aldehyde and ketone DNPH derivatives were used to quantify the results.

For alcohols, sample collection was performed by bubbling diluted exhaust through deionized water in a series of impingers. An aliquot of the solution was subsequently analyzed for alcohols using a gas chromatograph equipped with a flame ionization detector. External standards were used to quantify the results.

For each sample set, a background (dilution air) sample was collected. Tunnel blank samples were collected for each analyte as specified in Table 6.

4.3.6 Dioxins and Furans

As discussed above, sampling for dioxins and furans utilized an 8 by 10-inch Zefluor® filter followed by four 4 inch XAD cartridges. This approach was required to achieve the extremely low detection limits required for these analytes. The analytical protocol followed for analysis of dioxins and furans (PCDD or PCDF) is EPA Method 8290. The instruments used included a VG AutoSpec high resolution gas chromatograph/high resolution mass spectrometer (HRGC/HRMS), a Fisons AutoSpec Ultima HRGC/HRMS, and a Micromass AutoSpec Ultima HRGC/HRMS. The sample was spiked with a solution containing specified amounts of each of the nine isotopically ($^{13}C_{12}$) labeled PCDDs/PCDFs listed in the method. The sample was then extracted according to a matrix-specific extraction procedure and analyzed.

A tunnel background sample was collected as specified in Table 4.

4.3.7 Elemental Carbon/Organic Carbon

SwRI used the Sunset Laboratories semi-continuous instrument with a Zefluor® filter for OC analysis during tunnel conditioning and stabilization. SwRI used this method extensively during Project E-66. The use of this instrument was intended to support the sampling system conditioning efforts by providing information on the stability of OC emissions. These efforts were not successful because the engines went into active DPF regeneration at least two times during the 10 hours of conditioning. Due to the high temperatures experienced during active regeneration, the 10 hours of conditioning was deemed to be sufficient prior to starting the official testing.

For OC/EC collection and analysis during official testing, SwRI did not use the semi-continuous OC/EC analyzer. Instead, SwRI collected PM from the animal exposure chamber on a primary and a backup quartz filter. These filters were analyzed for OC/EC by DRI using thermal optical reflectance (TOR) and thermal optical transmittance (TOT).

4.3.8 Particulate- and Gas-Phase Organic Compounds

Among the many particulate and semi-volatile organic compounds (SVOC) are the following groups of compounds: PAH, oxyPAH, nitroPAH, hopanes/steranes, higher molecular weight alkanes, cycloalkanes, higher molecular weight aromatics, and certain polar organic compounds. Sampling was performed with an 8 by 10 inch Zefluor PM filter followed by four, 4-inch traps containing XAD-4 resin. For analysis, a Varian 4000 Ion Trap in electron impact (EI) mode, and a Varian 1200 triple quadrupole GC/MS operating in negative chemical ionization (CI) mode was used for nitroPAH compounds. Negative CI offers a superior sensitivity for the analysis of nitroPAH (approximately 100 times higher than EI or positive CI) and other compounds with electron-withdrawing substituents, but not for regular PAH and hydrocarbons. Because nitroPAH are expected to be present at a very low level, this superior sensitivity and selectivity was necessary.

Sampling materials were prepared by DRI and shipped to SwRI. Prior to sampling, XAD-4 resins were extracted with methanol followed by dichloromethane (CH_2Cl_2), using an Accelerated Solvent Extractor (Dionex 3000). The cleaned resin was dried in a vacuum oven heated to 40 ºC and stored in sealed glass containers in a clean freezer. The filters were cleaned by sonification in CH_2Cl_2 for 30 minutes, followed by another 30-minute sonification in methanol. The filters were then dried, placed in aluminum foil, and labeled. Each batch of pre-cleaned XAD-4 resin and approximately 10 percent of pre-cleaned filters was checked for purity by solvent extraction and GC/MS analysis of the extracts. The XAD-4 resins were assembled into glass cartridges (20 g of XAD) and stored in a clean freezer prior to shipment to SwRI.

All samples returned from SwRI were stored in a freezer prior to extraction. All samples were extracted within two weeks of being received at DRI.

Prior to extraction, the following deuterated internal standards were added to each filter and XAD sorbent: naphthalene-d8, biphenyl-d10, acenaphthene-d10, phenanthrene-d10, anthracene-d10, pyrene-d12, benz(a)anthracene-d12, chrysene-d12, benzo[e]pyrene-d12, benzo[a]pyrene-d12, benzo[g,h,i]perylene-d12, coronene-d12, cholestane-d6, hexadecane-d34, eicosane-d42, hexatriacontane-d74, 2-nitrodiphenyl-d9, 1-nitropyrne-d9, benzoic-d6 acid, phthalic 3,4,5,6-d4 acid, hexanoic-d11 acid, heptadecanoic-d33 acid, and myristic-d27 acid.

Filters and XAD-4 resins were extracted with dichloromethane using the Dionex ASE followed by acetone extraction under the same conditions. The dichloromethane extraction method has been reported to yield high recovery of PAH [8] and nitroPAH [9,10]. Dichloromethane extraction followed by acetone also gave good recovery for PAH, aliphatic hydrocarbons, cycloalkanes, hopanes, steranes, and polar organic compounds.

All extracts were then concentrated by rotary evaporation at 35°C under gentle vacuum to approximately 1 mL and filtered through a 0.2 μm PTFE disposal filter device (Whatman Pura discTM 25TF), rinsing the flask 3 times with 1 mL dichloromethane and acetone (50/50 by volume) each time. The extract was split into two fractions (polar and non-polar analyses) and was solvent exchanged to acetonitrile under ultra-high purity nitrogen.

The extracts were analyzed first by GC/MS for higher molecular weight (C>15) aliphatic hydrocarbons and cycloalkanes. Subsequently, the extracts were pre-cleaned by the solid-phase extraction technique. Superclean LC-SI SPE cartridges (Supelco) were sequentially eluted with hexane, and hexane/benzene (1:1). The hexane fraction contains the non-polar aliphatic hydrocarbons (alkanes), and hopanes and steranes, and the hexane/benzene fraction contains PAH and nitroPAH. These two fractions were concentrated to approximately 100 μL and analyzed by GC/MS for hopanes, steranes, PAH and oxyPAH. For nitroPAH, the extracts were further pre-cleaned by the solid-phase extraction technique, using aminopropyl (NH2) SPE cartridges (Waters), with sequential elution with hexane/DCM, 98/2 v/v and hexane/DCM 80/20 v/v as described by Bamford et al. [11]. For nitro- and dinitroPAH analysis, these fractions were further cleaned by semi-preparative normal-phase high performance liquid chromatography (HPLC) technique (Waters). The Chromegabond Amino Cyano 25 cm x 9.6 mm column (ES Industries, West Berlin, NJ) and isocratic elution with 20 percent DCM in hexane were used [11]. The fraction corresponding to nitro- and dinitroPAH was collected and analyzed by negative ion chemical ionization GC/MS. The fraction for the polar analysis was derivatized using a mixture of bis(trimethylsilyl)trifluoroacetamide and pyridine to convert the polar compounds into their trimethylsilyl derivatives for analysis of organic acids, phenol and cresol.

The filters and XAD® extracts were analyzed by GC/MS, using a Varian CP-3800 GC equipped with a CP8400 auto sampler and interfaced to a Varian 4000 Ion Trap. Due to the high sensitivity of Ion Trap MS, it was used for analysis of all gas-phase and particulate phase organic compounds, with the exception of the nitroPAH compounds, which utilized the electron impact (EI) ionization method. Injections (1 µL) were made in the splitless mode onto a 30m 5 percent phenylmethylsilicone fused-silica capillary column (DB-5ms, J&W Scientific or equivalent). Quantification of the individual compounds was obtained by the selective ion storage (SIS) technique, monitoring the molecular (or the most characteristic) ion of each compound of interest and the corresponding deuterated internal standard. Calibration curves for the GC/MS quantification were made for the most abundant and characteristic ion peaks of the compounds of interest using the deuterated species most closely matched in volatility and retention characteristics as internal standards. National Institute of Standards and Technology (NIST) Standard Reference Material (SRM) 1647 (certified PAH) with the addition of deuterated internal standards and of those compounds not present in the SRM (i.e., oxyPAH, nitroPAH, hopane, steranes, carpanes, hydrocarbons, cycloalkanes) were used to make calibration solutions. A six- to eight-level calibration was performed for each compound of interest and the calibration check (using median calibration standards) was run every 10 samples to check for accuracy of analyses. If the relative accuracy of measurement (defined as a percentage difference from the standard value) was greater than 20 percent, the instrument was recalibrated.

NitroPAH was analyzed using the Varian 1200 triple quadrupole gas chromatograph/mass spectrometer (GC/MS/MS) system with a CP-8400 auto sampler. The tandem MS/MS system allows for structural elucidation of unknown compounds with precursor, product and neutral loss scan. The GC interface allows for sensitive analyses of complex mixtures in electron impact (EI) as well as positive and negative chemical ionization (CI) mode. Negative CI offers superior sensitivity for the analysis of nitroPAH (approximately 100 times higher than EI or positive CI) that could be emitted from combustion sources, including motor vehicle engines. The sensitivity of this instrument in full scan EI/MS mode is approximately 1 pg/µl with a 20:1 signal-to-noise ratio (S/N). In EI/MS SIM mode it reaches 50 fg/ul with a 10:1 S/N. For negative CI, 10 fg/ul of octafluoronaphthalene gives a S/N of 20:1. This superior sensitivity offers the advantage of analyzing small samples collected during a short sampling time.

4.3.9 Nitrosamines

Nitrosamines were collected on Thermosorb/N adsorbent cartridges using a Teflon® sample probe. Samples were quantified using modified EPA Method TO-7, which specifies analysis by GC/MS. The cartridge samples were collected from the primary dilution tunnel. The cartridges were eluted with a mixture of 25 percent methanol and 75 percent dichloromethane. The first 1.8 ml was collected for the GC/MS analysis, using the Varian 1200 GC/MS/MS system operating in negative CI mode. Injections (1 ul) were made in the splitless mode onto a CP WAX 51 capillary column (25 m long, 0.25 mm id). Quantification of the individual compounds was obtained by the multiple ion detection (MID) technique, monitoring the molecular ion of each compound of interest and the corresponding deuterated internal standard.

4.3.10 Real Time PM Size, Number, Total and Soot Mass

Particle size distribution and number concentration were measured using a TSI EEPS, as shown in Figure 14. The instrument covers a particle size range from 5.6 nm to 560 nm, and reports the full size distribution measurement on a 10 Hz basis. The principle of operation is to charge particles and mobilize them to deposit on a series of electrometers, each representing a narrow particle size range. The current reading from each electrometer is converted to number concentration.

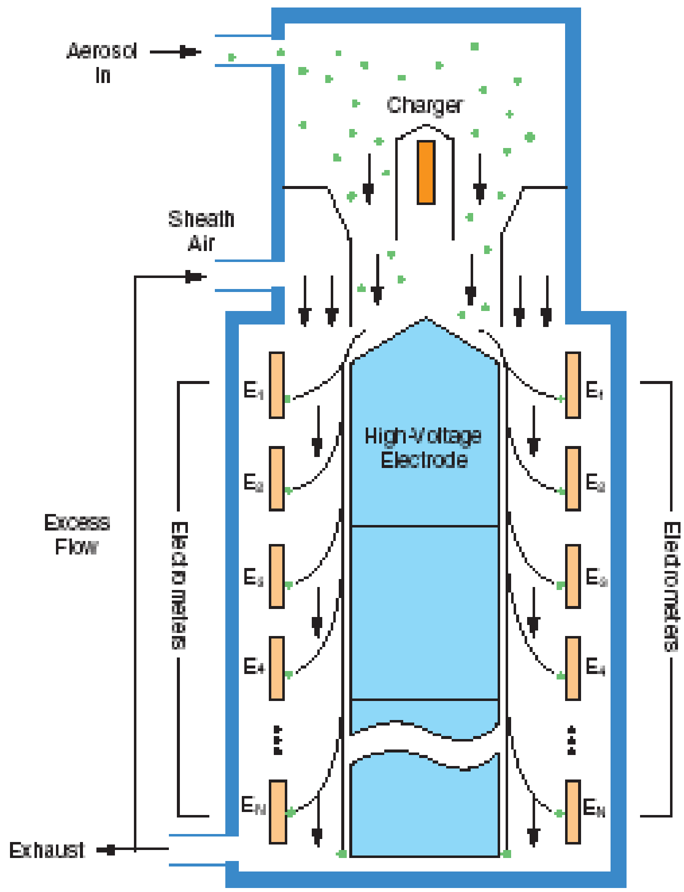


FIGURE 14. TSI ENGINE EXHAUST PARTICLE SIZER (EEPS)

The Dekati DMM-230, shown in Figure 15, was used for real time total particle mass emission measurement on a 1 Hz basis. The principle of operation is to charge particles and deposit the sub-30 nm particles on an electrometer by electric mobility and the rest of the particles on a series of electrometer stages by inertial impaction, with each electrometer representing a narrow aerodynamic size range. The current reading from each electrometer stage is converted into mass concentration using an average apparent density. The apparent density is determined by overlaying the calculated mobility diameter size distribution on top of the aerodynamic diameter size measured distribution.

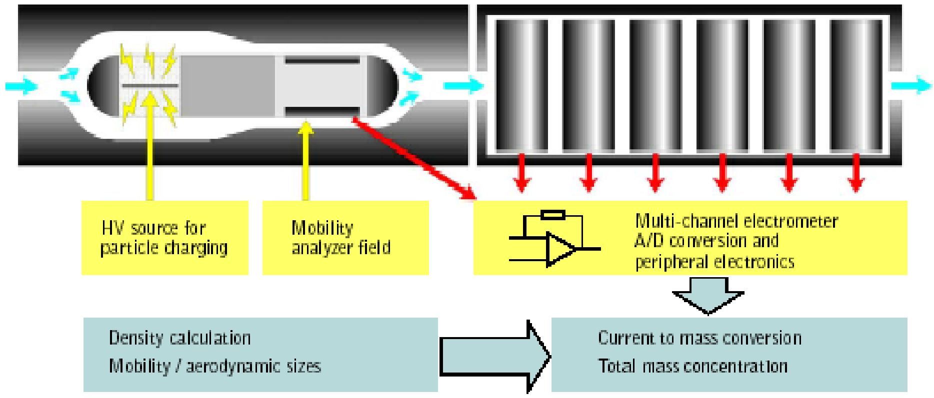


FIGURE 15. DEKATI MASS MONITOR (DMM-230)

An AVL MSS shown in Figure 16 was used for real time soot mass emission measurement on a 1 Hz basis. This instrument is widely used in engine emission activities focusing on the measurement of soot. The principle of operation is to slightly heat soot particles with a pulsed laser beam so the soot particles can generate a sound wave that can be detected by a sensitive microphone. The magnitude of the electric signal generated by the microphone indicates the mass concentration of soot.

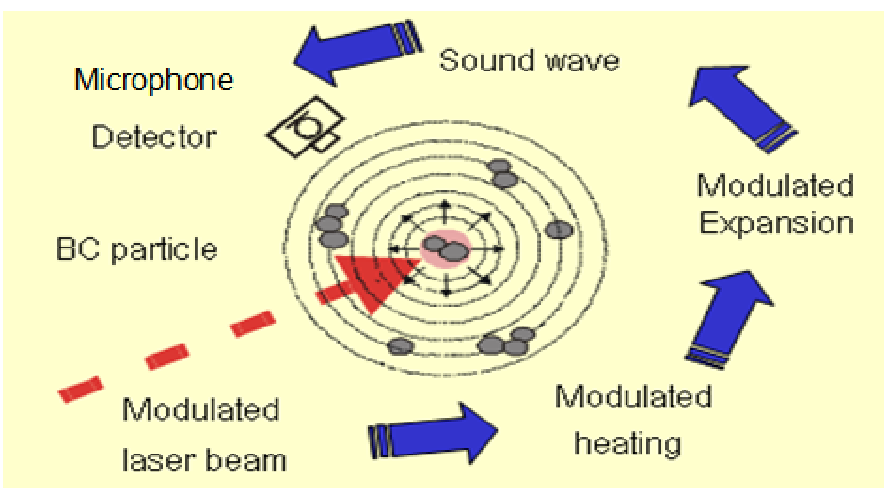


FIGURE 16. AVL MICRO-SOOT SENSOR (MSS)

4.4 Step-by-Step Engine Testing Procedures

Table 8 shows the general step-by-step procedures that were followed throughout the ACES program, including the various QA/QC checks used. Step 3 (tunnel blanks) were performed after tunnel clean up prior to testing Engine 1, and prior to testing Engine 5. The other steps applied to all engines. Each engine was conditioned for 20 minutes at rated engine power prior to performing the hot-start transient cycles. The engine was also conditioned for 20 minutes at rated engine power prior to performing one series of the CARB HHDDE 5-modes cycles.

TABLE 8. STEP-BY-STEP PROCEDURES

Steps	Action Items
1	Clean CVS tunnel (done only once before the first engine)
2	Set CVS flows as required
3	*Generate a tunnel blank with a sampling time of 20 minutes using a Teflo filter in accordance with Part 1065*
4	Perform all necessary calibration required under CFR Part 1065
5	Install engine in test cell
6	Power validate engine and compare the performance with that declared by the manufacturer
7	If Step 6 is acceptable, proceed to Step 8, otherwise resolve the performance issues
8	Condition engine and sampling system at near rated engine power for a period of 10 hours
9	Generate an engine torque map at wide open throttle in accordance with CFR Part 1065
10	Run practice FTP transient cycles, and perform the necessary tuning to pass cycle statistics
11	Perform three hot-start transient cycles and measure regulated emissions, particle size, number and mass using EEPS, DMM-230, and MSS if available
12	Perform three repeats of Mode 1, Mode 3, and Mode 5 taking regulated emissions with selected particle measurements as in Step 11
13	Compare all regulated brake specific emissions with those determined by the manufacturer
14	Resolve the differences, if any, between SwRI and the manufacturer results and proceed with the emission characterization
15	Condition engine and sampling system by performing an “forced” active DPF regeneration prior to an overnight soak
16	Perform one cold-start FTP while sampling for regulated and selected particle measurement as in Step 11
17	Perform three hot-start FTP cycles (without blow-by) with 20 minutes engine-off soak between cycles. Sample for all regulated and unregulated emission species on each run.
18	Condition engine and sampling system by performing an “forced” active DPF regeneration
19	Repeat Step 17, but route engine blow-by to the exhaust in accordance with CFR Part 1065
20	*Generate a tunnel blank with a sampling time of 20 minutes similar to that in Step 3*
21	Condition engine and sampling system by performing an “forced” active DPF regeneration
22	Perform two runs of CARBx-ICT for regulated and unregulated emissions with 20 minutes engine-off soak period between runs
23	Condition engine and sampling system by performing an “forced” active DPF regeneration
24	Perform two runs of CARBz-CH for regulated and unregulated emissions with 20 minutes engine-off soak between runs
25	*Generate a tunnel blank with a sampling time of 20 minutes, with similar measurements to that in Step 3*
26	Condition engine and sampling system by performing an “forced” active DPF regeneration
27	Perform one 16-Hour transient cycle over a period of two days. Sample for all regulated and unregulated emissions. On day 1, run a hot-start for the first 4-hour segment, bring the engine to low idle for 15 minutes, and run another 4-hour segment, then shut down engine. On day 2, run a cold-start for the first 4-hour segment, bring the engine to low idle for 15 minutes, and then run another 4-hour segment, and shut down engine.
28	Repeat Step 27 twice
29	Repeat Step 27 one more time and collect for dioxins/furans analysis only. (All engines, except Engine B)
30	*Generate a tunnel blank with a sampling time of 20 minutes while sampling as in Step 3*
31	*Generate a tunnel background for 16 hours while sampling as in Step 27*
32	*Generate a tunnel background for 16 hours while sampling as in Step 29*
33	*Repeats Steps 4 through 32 with Engine B, but skip Step 29*
34	*Repeats Steps 4 through 32 with Engine C*
35	*Repeats Steps 4 through 32 with Engine D*

5.0 RESULTS

This section includes all the regulated and unregulated emission species results. Active DPF regeneration took place during some of the runs, as indicated in Table 9. Active DPF regeneration is a state that is defined by the engine control module (ECM) attempting to regenerate the DPF by exhaust fuel injection (dosing), or by starting an exhaust burner, depending on the technology used. An active regeneration state may include times where dosing is not active due to a low exhaust temperature or other conditions. Although fuel injection may not be occurring, it is likely that the engine is still operating differently in an attempt to facilitate the regeneration process by intake air throttling or changing the EGR and VGT positioning. For engines using exhaust fuel injection, these measures are necessary to raise the exhaust temperature to the point where fuel injection may be enabled and the regeneration can proceed. An active regeneration state may include multiple, separate dosing events until the DPF is "clean." The length of the regeneration event thus is likely to depend on the duty cycle of the engine. More higher load (and therefore higher temperature) operation will allow the regeneration to proceed quicker, resulting in a shorter overall regeneration time. It should be emphasized that this does not necessarily apply to every regeneration method.

Engine C had a DPF crack failure during CARBx-ICT and CARBz-CH cycles; these data were excluded from the emission comparison results. The engine controller provided by the manufacturer was not properly configured for the test cell environment, and consequently would clear the DPF soot load status between tests. It is believed that the DPF failed when an uncontrolled regeneration event was triggered with an underestimated DPF soot load. Upon further investigation, the engine manufacturer identified a problem with the fuel injection system, and recommended replacing the engine. The engine was replaced with an identical engine, and testing resumed for the 16-Hour tests. The CARBx-ICT and CARBz-CH cycles were not re-run due to budgetary and project timing constraints.

Table 9 indicates when active regeneration occurred and how many times it occurred. The time listed for active regeneration is the time between the beginning and end of a regeneration state for the 16-Hour cycle. The regeneration state time listed could mean that exhaust fuel dosing is on continuously, or switched on and off, depending on engine load, speed, exhaust temperature, or other conditions. Thus, when an active regeneration state is triggered during the FTP cycle, it does not mean that active regeneration was occurring continuously for the entire FTP cycle time. It could be "on" for 1 to 5 minutes or for the entire time, again, depending on each engine manufacturer's strategy.

Because all the data in the results section will be reported on a brake-specific basis, Table 10 shows the average conversion multiplier for converting from brake-specific emissions to other units of interest such as fuel specific emissions, emissions rate, or concentration. The conversion multipliers were calculated based on the experimental data. For example, if the average brake-specific emission for Engine A, FTP-w, is 1 g/hp-hr for a particular compound, it will be 5.16 g/kg of fuel, 98.8 g/hr, and 172 mg/m^3 in the exhaust. If one is interested in determining the average concentration in the exposure chamber for this particular compound, one can then divide the exhaust concentration over the exposure chamber dilution ratio (46.15). It should be noted that the conversion from brake-specific emissions (g/hp-hr) to emission rate (g/hr) is based simply on the average power (hp) of the cycle.

TABLE 9. NUMBER OF ACTIVE REGENERATIONS PER TEST

Test Cycle	Number of Cycles	Number of Regenerations per Cycle			
		Engine A	Engine B	Engine C	Engine D
FTP-w	3	0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0
FTP-wo	3	1[c], 1[c], 1[c]	0, 0, 0	0, 0, 0	0, 0, 0
CARBx-ICT	2	0, 0	0, 0	DPF Crack	0, 0
CARBz-CH	2	0, 1[c]	0, 0, 0	DPF Crack	0, 0
16-Hour	3	1, 1, 1	2, 2, 3	1, 1, 1	1, 1, 1
Approximate Time of an Active Regeneration State, minutes (16-Hour Cycle Only)		75[a]	90[a]	30[a]	30[b]

[a] During this time, active regeneration via exhaust fuel injection or via an exhaust burner may or may not be on all the time. E.g. During the 75 minutes with Engine A, exhaust fuel injection may shut off at low exhaust temperature and may come back on at high temperature.
[b] For Engine D, this is the actual time of the active regeneration
[c] Dosing occurred during a portion of each FTP, but under the same active regeneration state.

TABLE 10. CONVERSION MULTIPLIER FROM BRAKE-SPECIFIC EMISSIONS TO OTHER UNITS

Test Name	Average Exhaust Temp, °C	Average Exhaust Flow, m^3/hr	Average CVS Dilution Ratio	Average Exposure Chamber Dilution Ratio	Average 8x10 Dilution Ratio	Conversion from Brake Specific to Fuel Specific (g/hp-hr to g/kg of fuel)	Conversion from Brake Specific to Emission Rate (g/hp-hr to g/hr)	Conversion from Brake Specific to Concentration (g/hp-hr to mg/m^3)
Engine A								
FTP-w	242	572	27.9	1.65	1.60	5.16	98.8	172.6
FTP-wo	246	572	28.7	1.63	1.62	4.89	98.3	171.7
CARBx-ICT	156	216	47.1	1.67	1.61	3.41	17.0	78.7
CARBz-CH	296	673	13.4	1.65	1.60	4.81	137.4	204.1
16 HR	273	550	24.6	1.62	1.89	5.31	108.4	197.0
Engine B								
FTP-w	239	513	29.9	1.60	1.84	4.94	94.7	184.7
FTP-wo	245	507	30.1	1.60	1.87	5.24	94.1	185.7
CARBx-ICT	99	275	34.6	1.70	1.77	4.49	19.6	71.4
CARBz-CH	299	588	16.0	1.73	1.90	5.64	138.5	235.4
16 HR	274	525	21.8	1.52	1.95	5.15	110.8	211.0
Engine C								
FTP-w	230	362	64.1	1.49	1.38	5.23	81.8	226.2
FTP-wo	230	359	64.1	1.49	1.56	5.27	81.0	225.7
CARBx-ICT	131	131	88.2	1.52	1.96	3.81	17.6	134.3
CARBz-CH	277	507	25.6	1.46	1.93	5.69	139.1	274.7
16 HR	260	402	42.7	1.59	2.10	5.64	105.5	262.3
Engine D								
FTP-w	262	482	42.4	1.57	1.86	5.52	101.5	210.5
FTP-wo	264	478	43.5	1.57	1.97	5.54	101.3	211.8
CARBx-ICT	138	262	39.3	1.61	1.94	4.21	20.5	78.4
CARBz-CH	314	594	19.5	1.59	1.84	5.82	147.5	248.2
16 HR	299	527	29.5	1.60	1.95	5.55	118.0	223.9

Based on Table 10, if the average brake-specific emissions for CARBx-ICT are a factor of 1.4 higher than the average emissions for the FTP, CARBz-CH, and the 16-Hour cycle, then the fuel-specific emissions for CARBx-ICT would be at levels similar to the other cycles because of the CARBx-ICT cycle's higher fuel consumption rate. CARBx-ICT brake-specific emissions, on average, would need to be a factor of 5.5, 8.3, and 6.5 higher than the brake-specific emissions for the FTP, CARBz-CH, and 16-Hour cycle, respectively, for the g/hr emissions rate to be the same. Thus, it is important to take into consideration these conversion factors when comparing emissions among the different engines and cycles.

If one assumes a typical fuel mileage (FM) for heavy-duty trucks, e.g. 6 miles per gallon, one can convert the brake specific emissions (BSE) from g/hp-hr to g/mile by using the following equation:

$$g/mile = [BSE]/[(BSFC/FD*FM]$$

BSFC is the measured brake specific fuel consumption in lb/hp-hr, and FD is the fuel density in lb/gallon (7.12 lb/gallon). The g/mile calculation conversion factor is not shown in Table 10. This was done to differentiate calculations based on measured values, such as those reported in Table 10, from calculations based on assumptions, such as the equation above.

Table 10 also includes the values of average exhaust temperature, exhaust flow rate, CVS dilution ratio, exposure chamber dilution ratio, and 8 x 10-inch filter dilution ratio. The average exhaust temperature is an indicator of the engine-out temperature before the aftertreatment system. This value indicates how much catalytic activity may occur in an aftertreatment system from one cycle to another. The average exhaust flow rate is given in units of standard cubic meters per hour, referenced to 20 degrees Celsius and 1 atmosphere pressure. The CVS dilution ratio (DR) is defined as follows:

$$\text{CVS DR} = \text{Total CVS Flow/Exhaust Flow}$$

where the total CVS flow includes both the CVS dilution air and the exhaust flow. The exposure chamber dilution ratio is the total dilution ratio from exhaust concentration to exposure chamber concentration and is defined as follows:

$$\text{Exposure Chamber DR} = \text{CVS DR*Secondary Exposure Chamber DR}$$

where the secondary exposure chamber DR is the ratio of the total exposure chamber flow to the sample flow extracted from the CVS. The 8 x 10-inch filter dilution ratio refers to the ratio from the exhaust concentration to the concentration measured by the 8 by 10-inch Zefluor® filter, XAD cartridges, and the four 47 mm filters. It is defined as:

$$\text{8x10 DR} = \text{CVS DR*Secondary 8 x 10 DR}$$

where the 8 x 10 secondary DR is the ratio of the total flow of the 8 x 10 system to the sample flow extracted from the CVS.

5.1 Fuel and Oil PAHs, Hopanes and Steranes

Figures 17, 18, and 19 show PAH concentration in the fuel and in fresh and used lube oil after 125 hours of degreening. PAH in the lube oil was at a much lower concentration than the PAH in the fuel. However, for PAH species such as coronene, dibenzopyrene and dibenzofluoranthene; little to no presence was detected in the fuel, although some presence was observed in the lube oil. PAH concentration in the lube oil was less than 0.5 ppm, except for Engine B, where it was 7.5 ppm for coronene and 28 ppm for benzo (ghi) perylene. It is not clear why the Engine B lube oil exhibited different concentrations than the other lube oils.

Figures 20 and 21 show the hopanes and steranes present in fresh and used lube oil. The highest hopanes and steranes concentration was found in Engine D's lube oil. Engine B lube hopanes were on the same order as Engine D, but the steranes were lower. Hopanes and steranes may be a good indicator of the lube oil's contribution to emissions, since they were not measured in the fuel. Appendix C includes the data on fuel and lube oil PAHs, and hopanes and steranes.

Figures 17 through 21 give a visual indication of the differences in PAHs, hopanes, and steranes concentrations (ratio of mass of species and mass of bulk liquid) between oil and fuel and among the different lube oils. For in depth information, interested readers should look at Appendix C that includes the actual data on fuel and lube oil PAHs, hopanes and steranes, along with the uncertainty or the limit of detection for each compound. It is worth noting that the majority of the data reported are above the limit of detection.

5.2 Cycle Work

Table 11 shows the work performed by each engine for each cycle tested. The cycle length is 20 minutes for the FTP, 39 minutes for CARBx-ICT, 48 minutes for CARBz-CH, and 16 hours for the 16-Hour cycle. Relative to the average engine power produced during the FTP cycle, the 16-Hour cycle was 10 percent higher, the CARBz-CH cycle was 37.5 percent higher, and the CARBx-ICT was 80 percent lower. Essentially, CARBx-ICT was at a much lighter engine load than that of the FTP, and it will only produce 20 percent of the work produced by the FTP per unit time.

The cycle work for each engine was very consistent, and the coefficient of variation, based on three repeats for the FTP and 16-Hour cycle, and two repeats for CARBx-ICT and CARBz-CH, was less than one percent for the majority of the runs, as shown in Table 11.

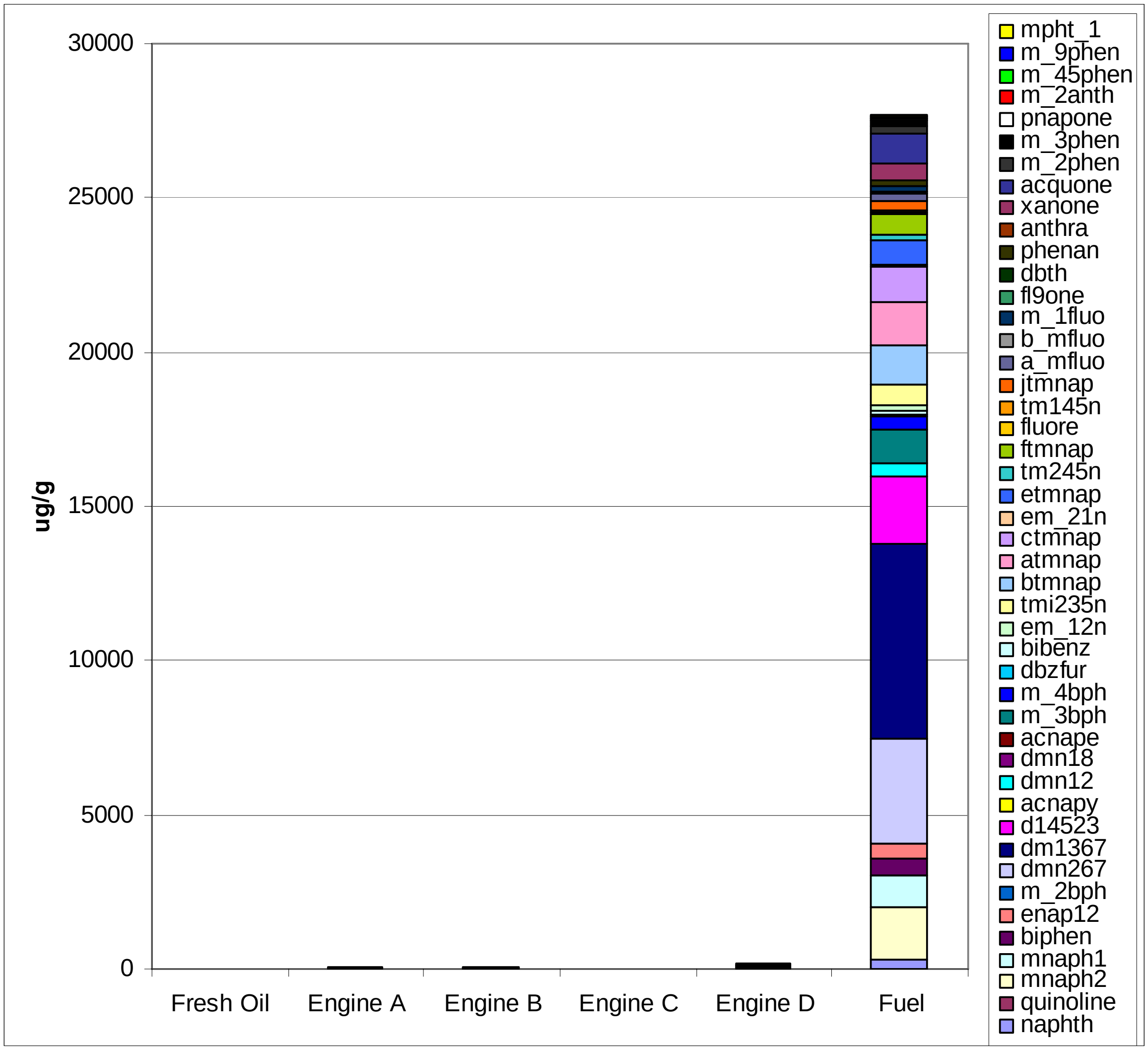


FIGURE 17. PAH CONCENTRATION IN LUBE OIL AND FUEL SHOWING A PARTIAL LIST OF FUEL PAH COMPOUNDS AT MUCH HIGHER CONCENTRATION THAN IN LUBE OIL

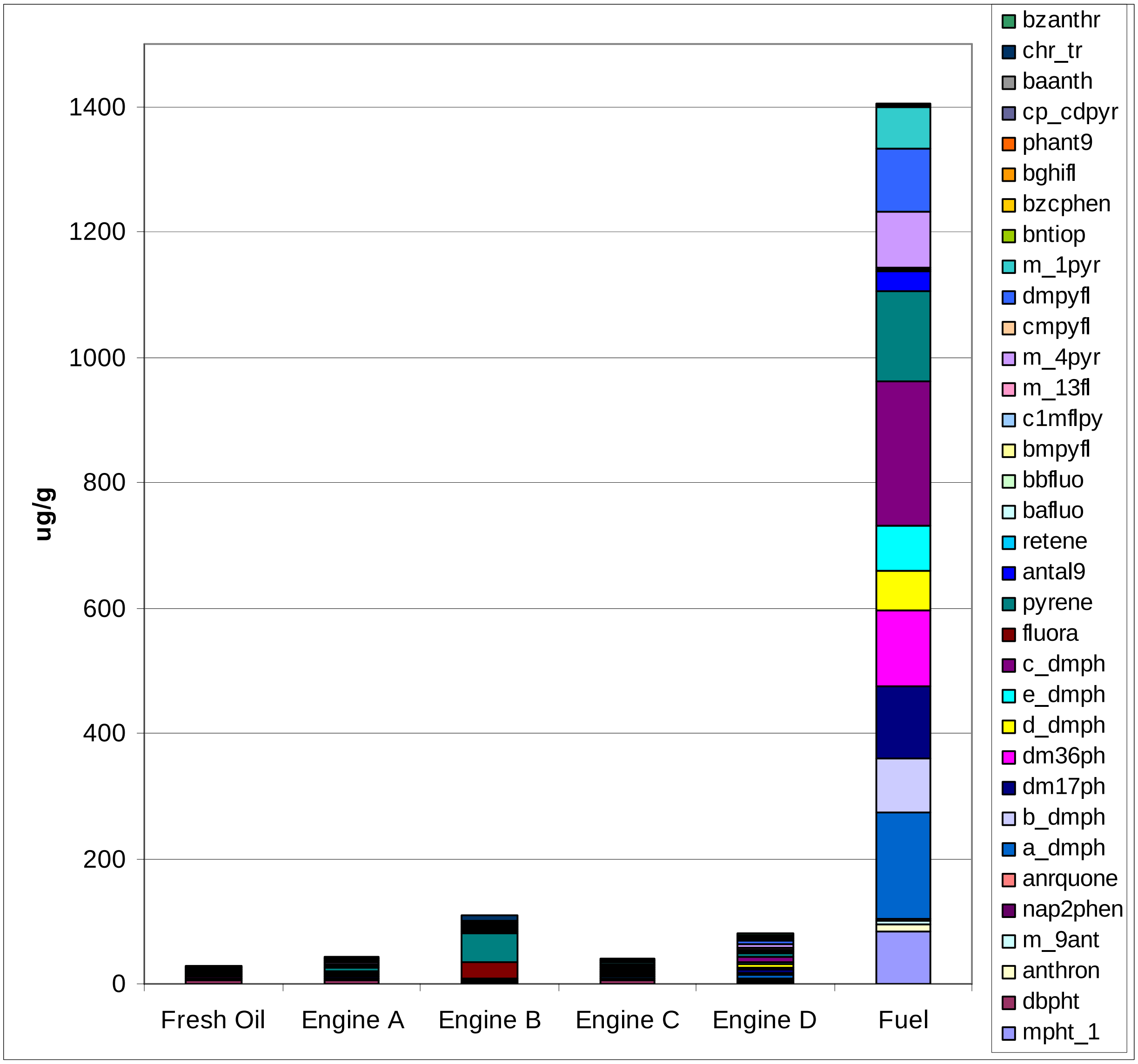


FIGURE 18. PAH CONCENTRATION IN LUBE OIL AND FUEL SHOWING A PARTIAL LIST OF FUEL PAH COMPOUNDS AT HIGHER CONCENTRATION THAN IN LUBE OIL

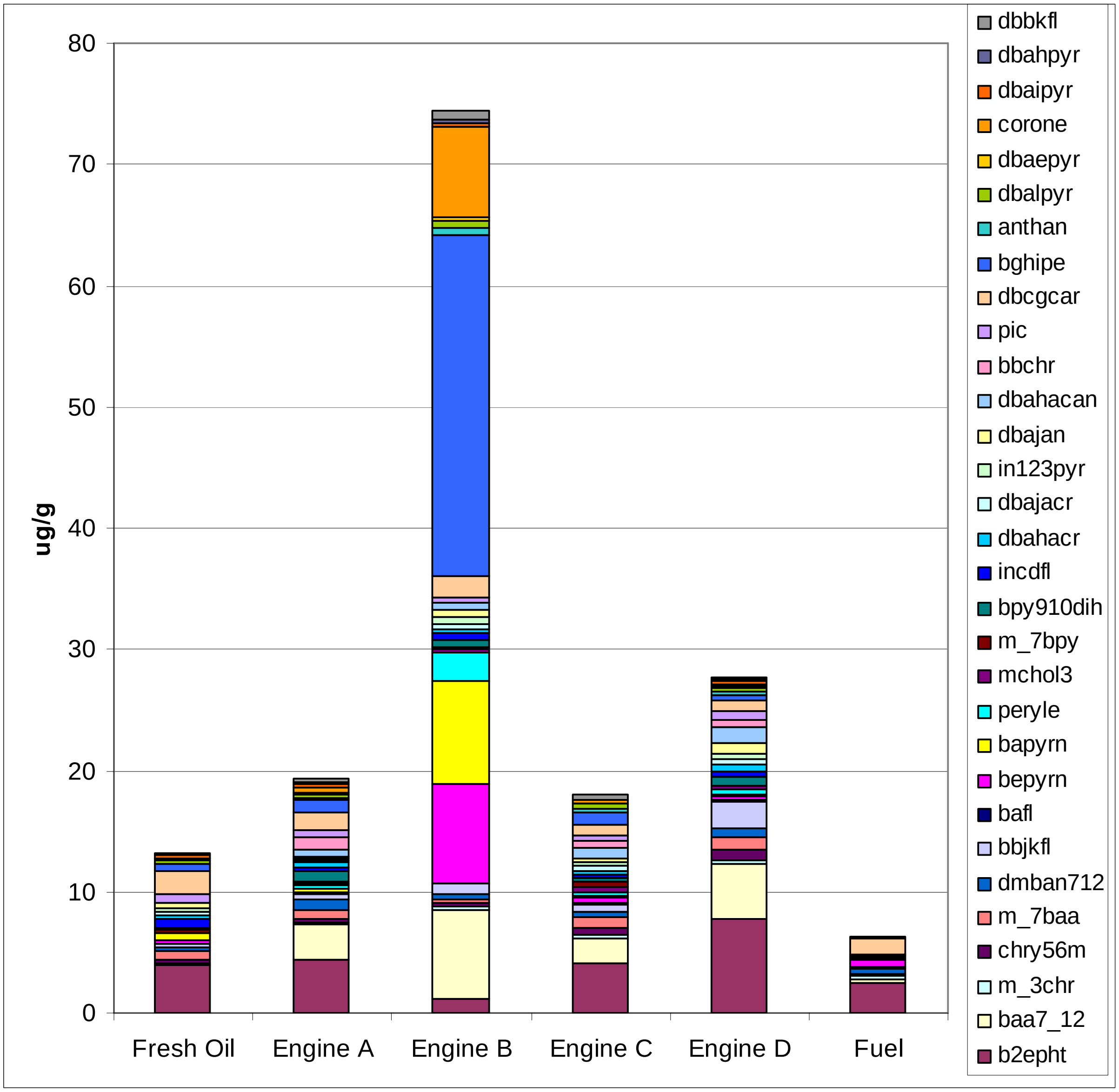


FIGURE 19. PAH CONCENTRATION IN LUBE OIL AND FUEL SHOWING A PARTIAL LIST OF FUEL PAH COMPOUNDS LOWER CONCENTRATION THAN IN LUBE OIL

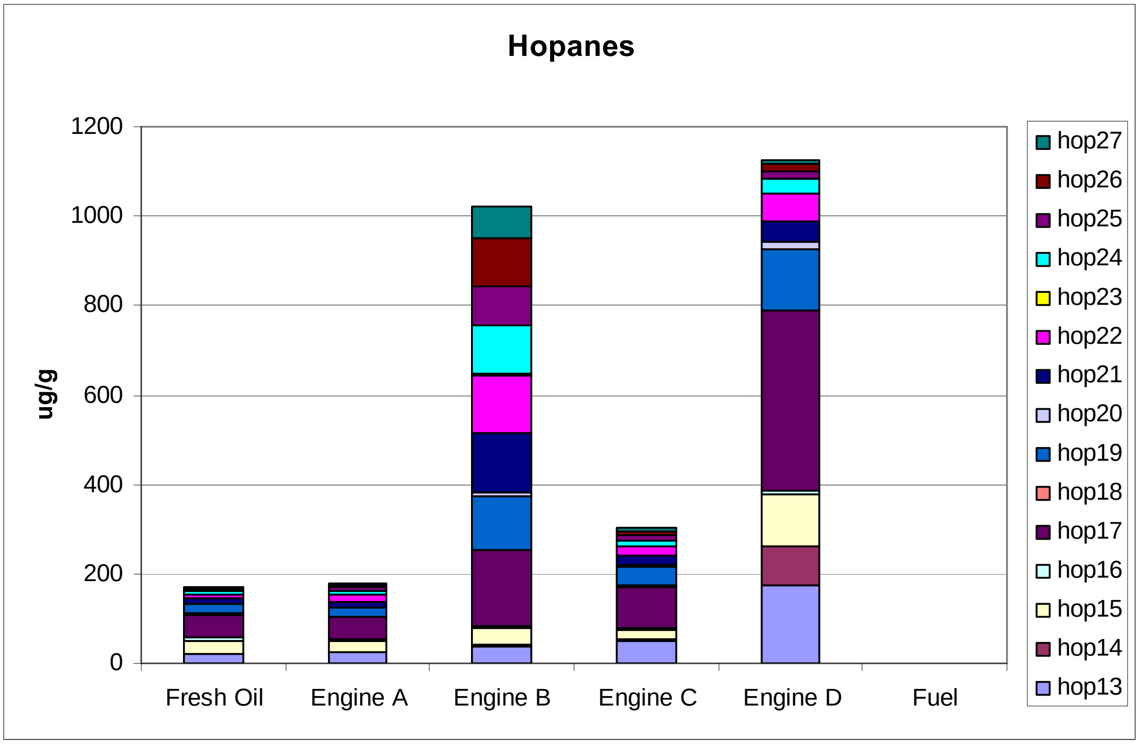


FIGURE 20. HOPANES CONCENTRATION IN LUBE OIL

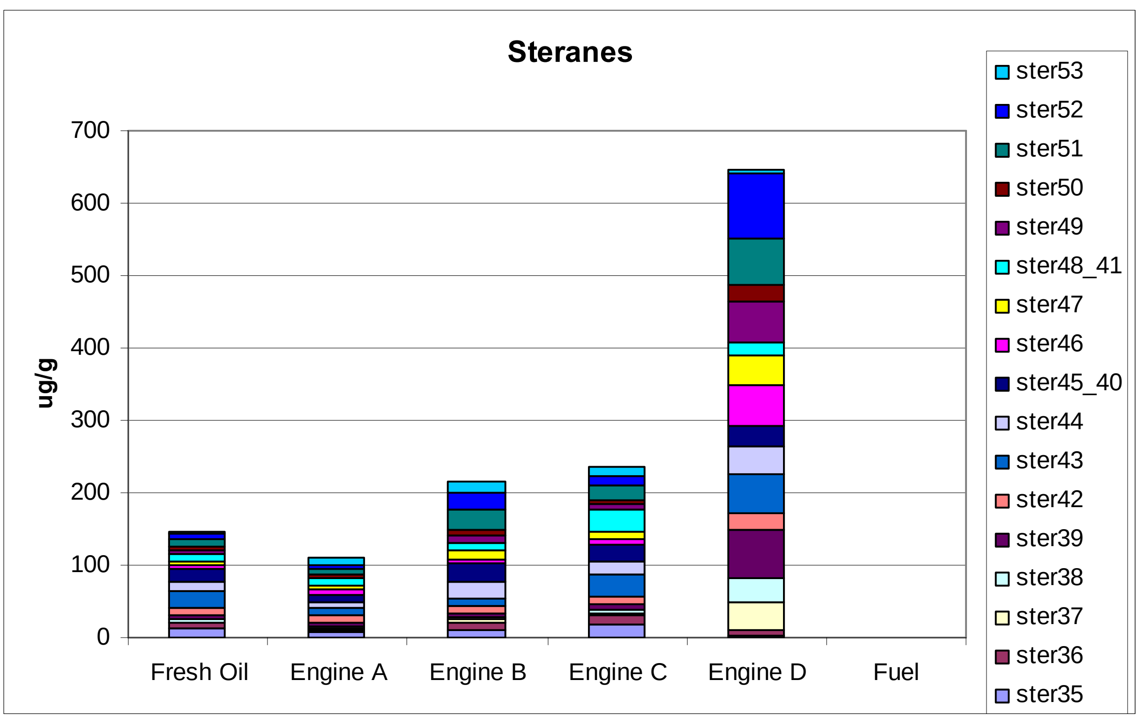


FIGURE 21. STERANES CONCENTRATION IN LUBE OIL

TABLE 11. ENGINE CYCLE WORK

Test Cycle	Test Number	Work, hp-hr					
		SwRI Elevation					Lovelace Elevation
		Engine A	Engine B	Engine C	Engine D	Engine B'	Engine B'
FTP-w	1	32.82	31.50	27.52	33.86	32.15	31.59
	2	32.93	31.45	27.13	33.72	32.12	31.57
	3	32.78	31.56	26.98	33.76	32.17	31.58
	Avg	**32.85**	**31.50**	**27.21**	**33.78**	**32.15**	**31.58**
	Stdev	**0.07**	**0.05**	**0.28**	**0.07**	**0.03**	**0.01**
	COV	**0.2%**	**0.2%**	**1.0%**	**0.2%**	**0.08%**	**0.03%**
FTP-wo	1	32.55	31.38	26.98	33.78	32.15	31.58
	2	32.74	31.26	26.95	33.71	32.14	31.55
	3	32.74	31.26	26.90	33.67	32.10	31.53
	Avg	**32.68**	**31.30**	**26.94**	**33.72**	**32.13**	**31.55**
	Stdev	**0.11**	**0.07**	**0.04**	**0.05**	**0.02**	**0.03**
	COV	**0.3%**	**0.2%**	**0.2%**	**0.2%**	**0.07%**	**0.08%**
CARBx-ICT	1	12.50	14.20	12.78	15.02	CARBx-ICT, CARBz-CH, and the 16-Hour cycle were not run with this engine	
	2	12.23	14.33	12.77	14.82		
	Avg	**12.36**	**14.26**	**12.78**	**14.92**		
	Stdev	**0.19**	**0.09**	**0.01**	**0.15**		
	COV	**1.6%**	**0.6%**	**0.0%**	**1.0%**		
CARBz-CH	1	108.71	109.60	103.42	116.39		
	2	108.10	108.98	107.61	116.38		
	Avg	**108.41**	**109.29**	**105.52**	**116.38**		
	Stdev	**0.43**	**0.44**	**2.97**	**0.01**		
	COV	**0.4%**	**0.4%**	**2.8%**	**0.0%**		
16-Hour	1	1711.28	1765.09	1686.03	1893.61		
	2	1728.85	1771.30	1687.33	1876.16		
	3	1753.33	1775.01	1687.78	1884.45		
	Avg	**1731.15**	**1770.47**	**1687.05**	**1884.74**		
	Stdev	**21.12**	**5.01**	**0.91**	**8.73**		
	COV	**1.2%**	**0.3%**	**0.1%**	**0.5%**		

5.3 Oxides of Nitrogen (Nitric Oxide, Nitrogen Dioxide, and Nitrous Oxide) Emissions

Table 12 and Figure 22 show the brake-specific NO_x emissions. Engine B', the backup engine, was tested at SwRI's elevation and at the Lovelace simulated elevation for regulated emissions only. At Lovelace elevation, the NO_x emission rate was 31 to 33 percent higher than that at SwRI's elevation.

Engine A through D showed different levels of NO_x emissions, depending on the cycle used. Average NO_x emissions ranged from 0.89 to 1.26 for the FTP-w, 2.97 to 5.22 for the CARBx-ICT, 0.93 to 1.72 for CARBz-CH, and from 1.19 to 1.49 for the 16-Hour cycle. The minimum increase of NO_x emissions between the FTP-w cycle and the 16 hour cycle was 6 percent for Engine D, while the maximum increase was 56 percent for Engine B. It is interesting to note that the brake specific NO_x emissions for Engines A and B increased by 37 and 35 percent, respectively for the CARBx-CH cycle relative to the FTP-w, while the emissions decreased by 17 percent for Engine D in the same comparison.

TABLE 12. BRAKE-SPECIFIC NO_X EMISSIONS

Test Cycle	Test Number	NO_x, g/hp-hr					
		SwRI Elevation					Lovelace Elevation
		Engine A	Engine B	Engine C	Engine D	Engine B'	Engine B'-Alt.
FTP-w	1	1.26	0.88	0.99	1.13	0.97	1.33
	2	1.25	0.89	1.05	1.11	0.97	1.31
	3	1.28	0.89	1.05	1.13	0.99	1.34
	Avg	**1.26**	**0.89**	**1.03**	**1.12**	**0.98**	**1.33**
	Stdev	**0.01**	**0.01**	**0.03**	**0.01**	**0.01**	**0.01**
	COV	**1.1%**	**0.8%**	**3.2%**	**0.9%**	**1.3%**	**1.0%**
FTP-wo	1	1.26	0.88	1.04	1.13	0.98	1.34
	2	1.25	0.91	1.04	1.10	0.96	1.29
	3	1.24	0.89	1.06	1.12	0.97	1.29
	Avg	**1.25**	**0.90**	**1.05**	**1.11**	**0.97**	**1.31**
	Stdev	**0.01**	**0.01**	**0.01**	**0.02**	**0.01**	**0.03**
	COV	**0.6%**	**1.5%**	**1.4%**	**1.6%**	**1.3%**	**2.1%**
CARBx-ICT	1	2.95	4.49	N/A	5.21		
	2	2.99	4.46	N/A	5.22		
	Avg	**2.97**	**4.48**	**N/A**	**5.22**		
	Stdev	**0.03**	**0.02**	**N/A**	**0.01**		
	COV	**1.0%**	**0.4%**	**N/A**	**0.1%**		
CARBz-CH	1	1.53	1.20	N/A	0.91		
	2	1.90	1.21	N/A	0.95		
	Avg	**1.72**	**1.20**	**N/A**	**0.93**		
	Stdev	**0.26**	**0.01**	**N/A**	**0.03**		
	COV	**15.0%**	**0.7%**	**N/A**	**3.1%**		
16-Hour	1	1.44	1.43	1.46	1.18		
	2	1.52	1.35	1.37	1.19		
	3	1.52	1.39	1.44	1.21		
	Avg	**1.49**	**1.39**	**1.42**	**1.19**		
	Stdev	**0.05**	**0.04**	**0.05**	**0.01**		
	COV	**3.2%**	**3.0%**	**3.5%**	**1.1%**		

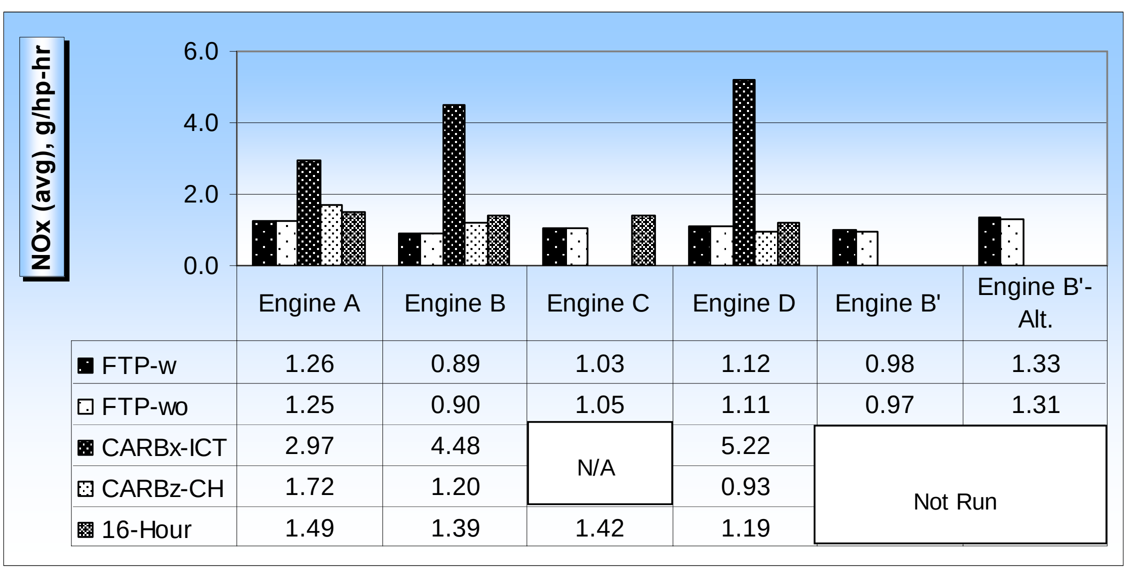


FIGURE 22. AVERAGE BRAKE-SPECIFIC NO_X EMISSIONS

Table 13 and Figure 23 show the NO emission results. Note that NO was not measured for Engine B'. The NO emissions profile may be different from the NO_x emissions profile, due to differences in NO_2 emissions, which are shown in Table 14 and Figure 24. NO_2 was not measured directly, but was calculated by taking the difference between NO_x and NO. Table 15 shows the NO_2 to NO_x ratio. The ratio ranged from 22 percent to 81 percent, depending on the cycle and engine used. Generally, the lowest ratio was observed with CARBx-ICT and the highest was observed with the FTP. NO_2 is produced in combustion, depending on the combustion strategy and temperature and the amount of EGR used. Furthermore, noble metals in the DOC and/or the DPF, particularly platinum, can convert NO to NO_2. Since the engine-out NO_2 is not known, it is unknown what the NO_2 percent increase is due to the catalyzed aftertreatment devices.

Table 16 and Figure 25 show the N_2O emissions. In general, the N_2O emissions represent less than one percent of total NO_x emissions.

5.4 Carbon Monoxide Emissions

The 2007 CO emission standard is 15.5 g/hp-hr. Table 17 and Figure 26 show the brake-specific CO emissions for all engines. Overall, CO emission levels were much lower than the standard for all engines and all cycles. The higher CO emissions with the CARBx-ICT cycle may suggest lower catalyst activity in oxidizing CO to CO_2 at the lower exhaust temperatures occurring during this low-power test cycle.

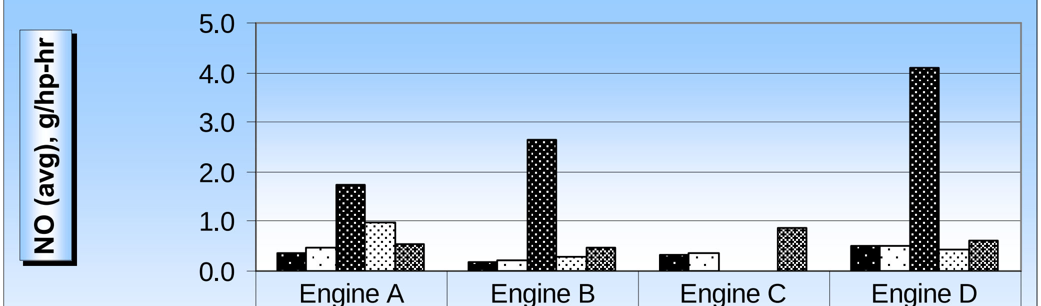
5.5 Total Hydrocarbon, Methane, and Non-Methane Hydrocarbon

The NMHC emission standard for 2007 and beyond is 0.14 g/hp-hr. NMHC was determined by taking the difference between THC and CH_4. Tables 18, 19, and 20 show the brake-specific emissions for THC, CH_4, and NMHC, respectively. Similarly, Figures 27, 28, and 29 show the average brake specific emissions for all engines and cycles tested. Because the concentrations in the CVS tunnel were very close to that in the CVS dilution air, the data were noisy after performing a background correction per CFR Part 1065. In general, NMHC emissions were much lower than the 2007 standard.

The same observation made about CO for the CARBx-ICT cycle can also be made about hydrocarbons. Due to the low exhaust temperatures of CARBx-ICT, the catalyzed DOC/DPF or DPF only may have provided less HC oxidation resulting in higher emissions than from the rest of the cycles. So, even on an emission rate basis in g/hr, CARBx-ICT will typically generate higher emissions than the rest of the cycles.

TABLE 13. NO EMISSIONS

Test Cycle	Test Number	NO, g/hp-hr			
		Engine A	Engine B	Engine C	Engine D
FTP-w	1	0.35	0.17	0.34	0.54
	2	0.37	0.11	0.34	0.50
	3	0.37	0.22	0.35	0.50
	Avg	**0.36**	**0.16**	**0.34**	**0.51**
	Stdev	**0.01**	**0.06**	**0.01**	**0.02**
	COV	**2.9%**	**33.8%**	**1.7%**	**3.9%**
FTP-wo	1	0.47	0.21	0.41	0.51
	2	0.44	0.21	0.35	0.53
	3	0.47	0.26	0.35	0.48
	Avg	**0.46**	**0.23**	**0.37**	**0.51**
	Stdev	**0.02**	**0.03**	**0.03**	**0.03**
	COV	**4.7%**	**11.8%**	**8.4%**	**5.2%**
CARBx-ICT	1	1.62	2.73	N/A	3.82
	2	1.87	2.54	N/A	4.36
	Avg	**1.75**	**2.64**	**N/A**	**4.09**
	Stdev	**0.18**	**0.13**	**N/A**	**0.38**
	COV	**10.3%**	**5.1%**	**N/A**	**9.3%**
CARBz-CH	1	0.64	0.29	N/A	0.42
	2	1.31	0.30	N/A	0.45
	Avg	**0.98**	**0.30**	**N/A**	**0.44**
	Stdev	**0.47**	**0.01**	**N/A**	**0.02**
	COV	**48.5%**	**3.2%**	**N/A**	**5.5%**
16-Hour	1	0.53	0.49	0.74	0.62
	2	0.57	0.45	0.87	0.62
	3	0.52	0.50	0.98	0.66
	Avg	**0.54**	**0.48**	**0.86**	**0.63**
	Stdev	**0.02**	**0.03**	**0.12**	**0.02**
	COV	**4.1%**	**5.4%**	**13.7%**	**3.5%**

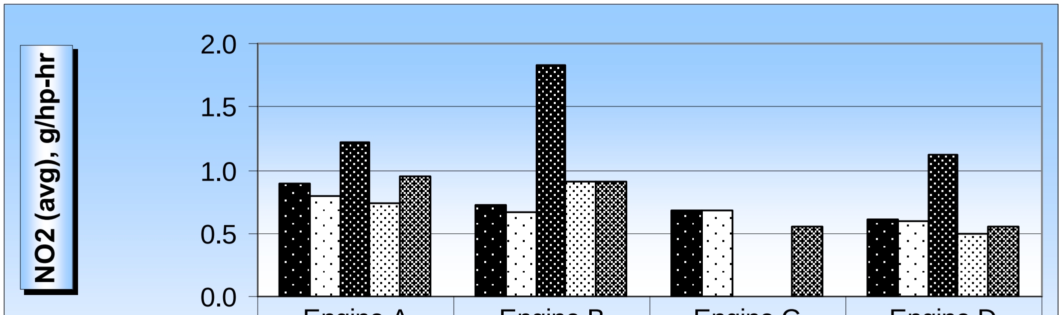


	Engine A	Engine B	Engine C	Engine D
FTP-w	0.36	0.16	0.34	0.51
FTP-wo	0.46	0.23	0.37	0.51
CARBx-ICT	1.75	2.64	N/A	4.09
CARBz-CH	0.98	0.30		0.44
16-Hour	0.54	0.48	0.86	0.63

FIGURE 23. AVERAGE BRAKE-SPECIFIC NO EMISSIONS

TABLE 14. BRAKE-SPECIFIC NO_2 EMISSIONS

Test Cycle	Test Number	NO_2, g/hp-hr			
		Engine A	**Engine B**	**Engine C**	**Engine D**
FTP-w	1	0.90	0.71	0.65	0.59
	2	0.89	0.79	0.71	0.61
	3	0.90	0.68	0.70	0.62
	Avg	**0.90**	**0.72**	**0.69**	**0.61**
	Stdev	**0.01**	**0.06**	**0.03**	**0.02**
	COV	**1.0%**	**7.8%**	**5.0%**	**2.8%**
FTP-wo	1	0.79	0.67	0.64	0.60
	2	0.82	0.70	0.68	0.57
	3	0.77	0.64	0.71	0.64
	Avg	**0.79**	**0.67**	**0.68**	**0.60**
	Stdev	**0.02**	**0.03**	**0.04**	**0.04**
	COV	**2.9%**	**4.8%**	**5.9%**	**6.1%**
CARBx-ICT	1	1.33	1.75	N/A	1.38
	2	1.11	1.92	N/A	0.86
	Avg	**1.22**	**1.84**	**N/A**	**1.12**
	Stdev	**0.15**	**0.12**	**N/A**	**0.37**
	COV	**12.6%**	**6.6%**	**N/A**	**32.8%**
CARBz-CH	1	0.89	0.90	N/A	0.49
	2	0.59	0.90	N/A	0.50
	Avg	**0.74**	**0.90**	**N/A**	**0.50**
	Stdev	**0.22**	**0.00**	**N/A**	**0.00**
	COV	**29.4%**	**0.1%**	**N/A**	**0.9%**
16-Hour	1	0.90	0.94	0.72	0.56
	2	0.95	0.90	0.49	0.57
	3	1.00	0.89	0.46	0.55
	Avg	**0.95**	**0.91**	**0.56**	**0.56**
	Stdev	**0.05**	**0.03**	**0.14**	**0.01**
	COV	**4.9%**	**3.0%**	**25.1%**	**1.7%**



	Engine A	Engine B	Engine C	Engine D
FTP-w	0.90	0.72	0.69	0.61
FTP-wo	0.79	0.67	0.68	0.60
CARBx-ICT	1.22	1.84	N/A	1.12
CARBz-CH	0.74	0.90		0.50
16-Hour	0.95	0.91	0.56	0.56

FIGURE 24. AVERAGE BRAKE-SPECIFIC NO_2 EMISSIONS

TABLE 15. NO_2/NO_X RATIO

NO_2/NO_x Ratio, %				
	Engine A	**Engine B**	**Engine C**	**Engine D**
FTP-w	71%	81%	67%	54%
FTP-wo	63%	75%	65%	54%
CARBx-ICT	41%	41%	N/A	22%
CARBz-CH	43%	75%	N/A	53%
16-Hour	64%	65%	39%	47%

TABLE 16. BRAKE-SPECIFIC N_2O EMISSIONS

Test Cycle	Test Number	N_2O, g/hp-hr SwRI Elevation Engine A	Engine B	Engine C	Engine D
FTP-w	1	0.0192	0.0041	0.0285	0.0070
	2	0.0205	0.0031	0.0210	0.0117
	3	0.0175	0.0077	0.0206	0.0119
	Avg	**0.0190**	**0.0050**	**0.0234**	**0.0102**
	Stdev	**0.0015**	**0.0025**	**0.0044**	**0.0028**
	COV	**1.1%**	**0.8%**	**3.2%**	**0.9%**
FTP-wo	1	0.0339	0.0033	0.0390	0.0127
	2	0.0283	0.0030	0.0200	0.0123
	3	0.0296	0.0032	0.0187	0.0124
	Avg	**0.0306**	**0.0032**	**0.0259**	**0.0125**
	Stdev	**0.0030**	**0.0001**	**0.0114**	**0.0002**
	COV	**0.6%**	**1.5%**	**1.4%**	**1.6%**
CARBx-ICT	1	0.0871	0.0296	N/A	0.0295
	2	0.0866	0.0399	N/A	0.0294
	Avg	**0.0868**	**0.0348**	**N/A**	**0.0294**
	Stdev	**0.0003**	**0.0073**	**N/A**	**0.0000**
	COV	**1.0%**	**0.4%**	**N/A**	**0.1%**
CARBz-CH	1	0.0117	0.0023	N/A	0.0055
	2	0.0132	0.0023	N/A	0.0057
	Avg	**0.0124**	**0.0023**	**N/A**	**0.0056**
	Stdev	**0.0011**	**0.0000**	**N/A**	**0.0002**
	COV	**1.0%**	**0.4%**	**N/A**	**0.1%**
16-Hour	1	0.0140	0.0059	0.0130	0.0095
	2	0.0150	0.0054	0.0100	0.0078
	3	0.0141	0.0060	0.0099	0.0094
	Avg	**0.0143**	**0.0057**	**0.0110**	**0.0089**
	Stdev	**0.0006**	**0.0003**	**0.0017**	**0.0009**
	COV	**3.2%**	**3.0%**	**15.8%**	**1.1%**

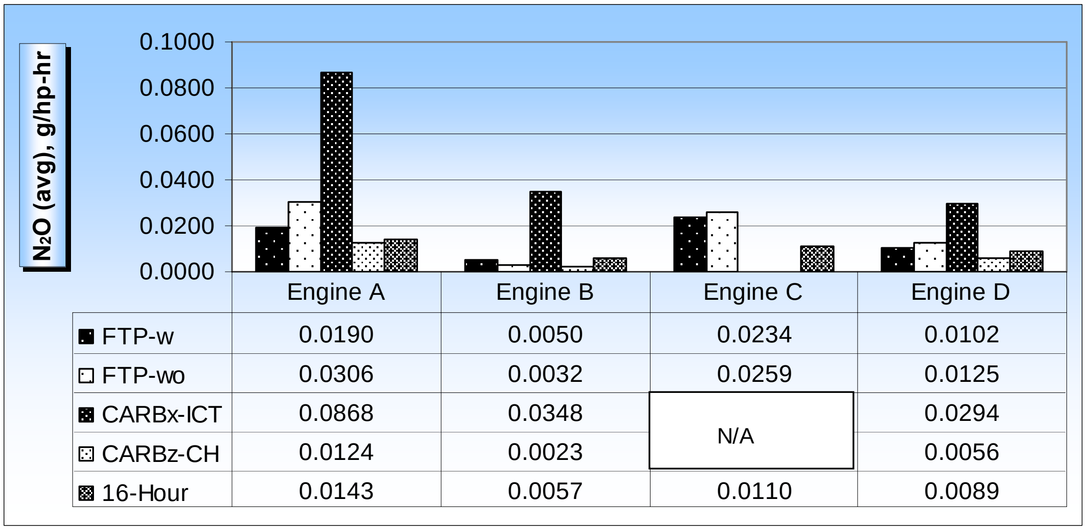
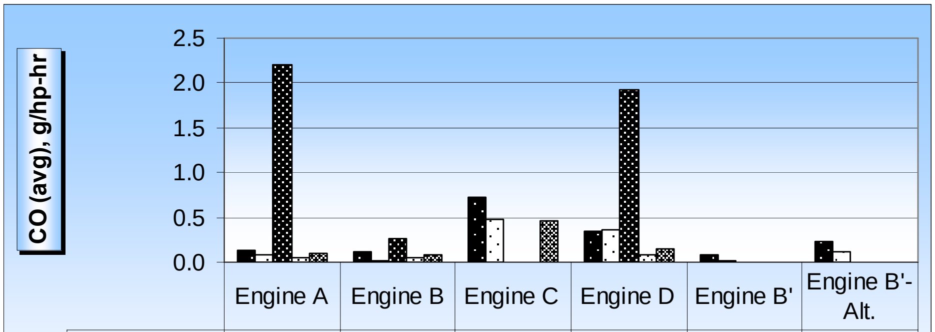


FIGURE 25. AVERAGE BRAKE-SPECIFIC N_2O EMISSIONS

TABLE 17. BRAKE-SPECIFIC CO EMISSIONS

Test Cycle	Test Number	CO, g/hp-hr					
		SwRI Elevation					Lovelace Elevation
		Engine A	Engine B	Engine C	Engine D	Engine B'	Engine B'-Alt.
FTP-w	1	0.11	0.12	1.14	0.36	0.089	0.334
	2	0.16	0.12	0.51	0.35	0.085	0.148
	3	0.12	0.10	0.51	0.33	0.066	0.189
	Avg	**0.13**	**0.11**	**0.72**	**0.35**	**0.080**	**0.224**
	Stdev	**0.02**	**0.01**	**0.37**	**0.01**	**0.012**	**0.097**
	COV	**17.7%**	**12.0%**	**51.0%**	**4.3%**	**15.0%**	**43.5%**
FTP-wo	1	0.09	0.02	0.49	0.35	0.020	0.189
	2	0.08	0.02	0.52	0.37	0.001	0.115
	3	0.05	0.03	0.44	0.36	0.005	0.060
	Avg	**0.08**	**0.02**	**0.48**	**0.36**	**0.009**	**0.121**
	Stdev	**0.02**	**0.01**	**0.04**	**0.01**	**0.010**	**0.065**
	COV	**27.6%**	**30.4%**	**8.2%**	**3.0%**	**119.3%**	**53.6%**
CARBx-ICT	1	2.32	0.24	N/A	2.04	CARBx-ICT, CARBz-CH, and the 16-Hour cycle were not run with this engine	
	2	2.07	0.30	N/A	1.81		
	Avg	**2.20**	**0.27**	**N/A**	**1.92**		
	Stdev	**0.18**	**0.04**	**N/A**	**0.16**		
	COV	**8.0%**	**16.2%**	**N/A**	**8.4%**		
CARBz-CH	1	0.04	0.05	N/A	0.10		
	2	0.05	0.06	N/A	0.07		
	Avg	**0.04**	**0.05**	**N/A**	**0.09**		
	Stdev	**0.00**	**0.00**	**N/A**	**0.01**		
	COV	**10.8%**	**9.5%**	**N/A**	**17.0%**		
16-Hour	1	0.09	0.09	0.43	0.15		
	2	0.10	0.08	0.48	0.16		
	3	0.10	0.07	0.46	0.14		
	Avg	**0.09**	**0.08**	**0.46**	**0.15**		
	Stdev	**0.00**	**0.01**	**0.03**	**0.01**		
	COV	**2.9%**	**12.0%**	**5.7%**	**7.9%**		



	Engine A	Engine B	Engine C	Engine D	Engine B'	Engine B'-Alt.
FTP-w	0.13	0.11	0.72	0.34	0.080	0.224
FTP-wo	0.08	0.02	0.48	0.36	0.009	0.121
CARBx-ICT	2.20	0.27	N/A	1.92	Not Run	
CARBz-CH	0.04	0.05		0.09		
16-Hour	0.09	0.08	0.46	0.15		

FIGURE 26. AVERAGE BRAKE-SPECIFIC CO EMISSIONS

TABLE 18. BRAKE-SPECIFIC THC EMISSIONS

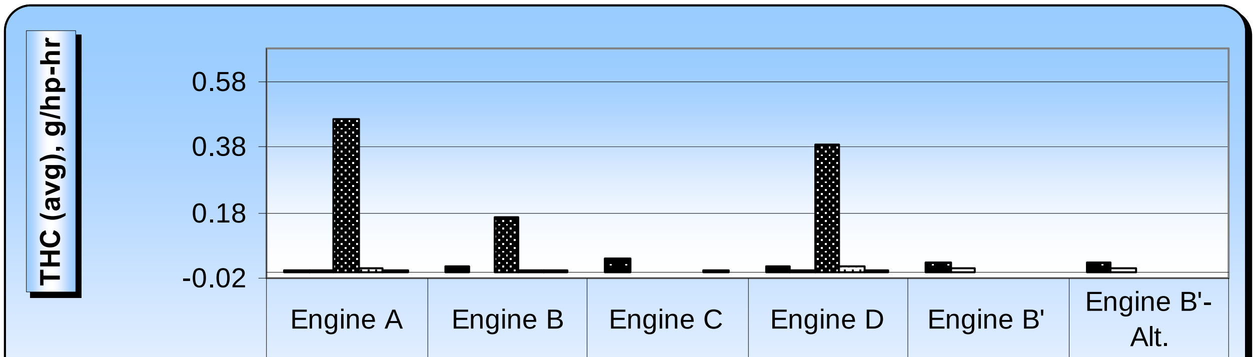
Test Cycle	Test Number	THC, g/hp-hr					
		SwRI Elevation					Lovelace Elevation
		Engine A	Engine B	Engine C	Engine D	Engine B'	Engine B'
FTP-w	1	0.005	0.020	0.055	0.016	0.035	0.029
	2	0.007	0.027	0.044	0.015	0.026	0.021
	3	0.007	0.002	0.026	0.023	0.025	0.024
	Avg	**0.006**	**0.016**	**0.042**	**0.018**	**0.029**	**0.025**
	Stdev	**0.001**	**0.013**	**0.015**	**0.005**	**0.005**	**0.004**
	COV	**18.4%**	**78.1%**	**35.7%**	**25.5%**	**18.6%**	**16.1%**
FTP-wo	1	0.006	0.008	-0.007	0.011	0.011	0.024
	2	0.001	-0.011	-0.001	0.004	0.005	0.001
	3	0.002	-0.004	0.002	-0.001	0.008	-0.001
	Avg	**0.003**	**-0.002**	**-0.002**	**0.005**	**0.008**	**0.008**
	Stdev	**0.002**	**0.010**	**0.005**	**0.006**	**0.003**	**0.014**
	COV	**79.2%**	**-426.3%**	**-236.9%**	**122.0%**	**35.5%**	**166.4%**
CARBx-ICT	1	0.455	0.131	N/A	0.407	CARBx-ICT, CARBz-CH, and the 16-Hour cycle were not run with this engine	
	2	0.475	0.199	N/A	0.368		
	Avg	**0.465**	**0.165**	**N/A**	**0.388**		
	Stdev	**0.014**	**0.048**	**N/A**	**0.027**		
	COV	**3.0%**	**29.3%**	**N/A**	**7.1%**		
CARBz-CH	1	0.008	0.005	N/A	0.017		
	2	0.008	0.004	N/A	0.018		
	Avg	**0.008**	**0.004**	**N/A**	**0.018**		
	Stdev	**0.001**	**0.001**	**N/A**	**0.000**		
	COV	**6.3%**	**23.3%**	**N/A**	**2.8%**		
16-Hour	1	0.007	0.006	-0.002	0.004		
	2	0.000	0.005	0.003	0.007		
	3	0.005	0.000	0.013	0.008		
	Avg	**0.004**	**0.004**	**0.005**	**0.007**		
	Stdev	**0.003**	**0.003**	**0.008**	**0.002**		
	COV	**80.7%**	**84.8%**	**160.6%**	**30.3%**		

TABLE 19. BRAKE-SPECIFIC CH_4 EMISSIONS

Test Cycle	Test Number	CH_4, g/hp-hr					
		SwRI Elevation					Lovelace Elevation
		Engine A	Engine B	Engine C	Engine D	Engine B'	Engine B'
FTP-w	1	0.009	0.019	0.024	0.007	0.026	0.011
	2	0.009	0.022	0.003	0.009	0.017	0.011
	3	0.010	0.036	0.013	0.010	0.017	0.009
	Avg	**0.009**	**0.025**	**0.014**	**0.009**	**0.020**	**0.010**
	Stdev	**0.001**	**0.009**	**0.011**	**0.002**	**0.005**	**0.001**
	COV	**6.6%**	**35.2%**	**77.8%**	**20.5%**	**27.0%**	**0.1%**
FTP-wo	1	-0.008	0.013	0.012	0.004	0.017	0.009
	2	0.012	0.012	0.003	0.008	0.011	0.006
	3	0.011	0.015	0.013	0.011	0.017	0.005
	Avg	**0.005**	**0.014**	**0.010**	**0.008**	**0.015**	**0.007**
	Stdev	**0.011**	**0.002**	**0.006**	**0.003**	**0.003**	**0.002**
	COV	**238.9%**	**11.5%**	**57.8%**	**42.6%**	**22.3%**	**28.0%**
CARBx-ICT	1	0.062	0.028	N/A	0.033	CARBx-ICT, CARBz-CH, and the 16-Hour cycle were not run with this engine	
	2	0.058	0.019	N/A	0.063		
	Avg	**0.060**	**0.023**	**N/A**	**0.048**		
	Stdev	**0.003**	**0.006**	**N/A**	**0.021**		
	COV	**5.3%**	**28.0%**	**N/A**	**44.9%**		
CARBz-CH	1	0.005	0.006	N/A	0.005		
	2	0.008	0.007	N/A	0.006		
	Avg	**0.007**	**0.007**	**N/A**	**0.006**		
	Stdev	**0.002**	**0.001**	**N/A**	**0.001**		
	COV	**30.1%**	**13.7%**	**N/A**	**9.6%**		
16-Hour	1	0.007	0.028	0.022	0.007		
	2	0.003	0.007	0.000	0.006		
	3	0.006	0.017	0.013	0.009		
	Avg	**0.005**	**0.017**	**0.012**	**0.007**		
	Stdev	**0.002**	**0.010**	**0.011**	**0.001**		
	COV	**42.8%**	**59.6%**	**94.1%**	**19.7%**		

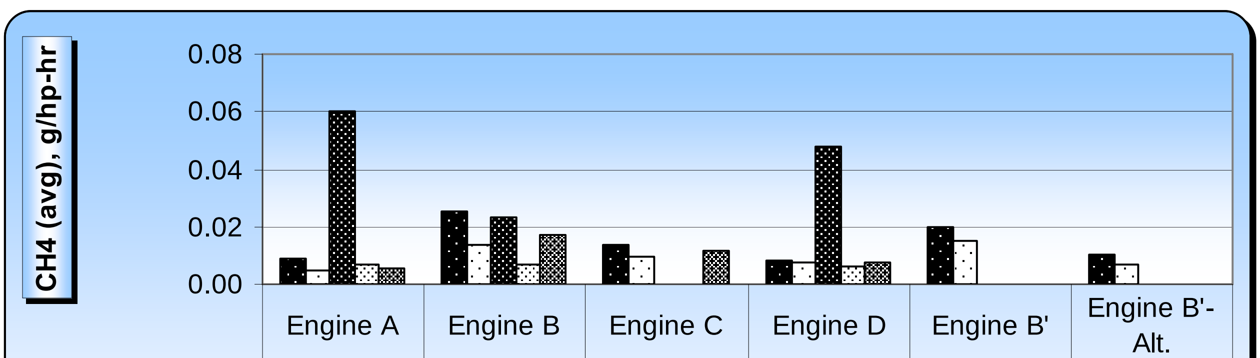
TABLE 20. BRAKE-SPECIFIC NMHC EMISSIONS

Test Cycle	Test Number	NMHC, g/hp-hr					
		SwRI Elevation					Lovelace Elevation
		Engine A	Engine B	Engine C	Engine D	Engine B'	Engine B'
FTP-w	1	-0.004	0.001	0.031	0.009	0.011	0.019
	2	-0.002	0.005	0.041	0.006	0.011	0.011
	3	-0.003	-0.034	0.013	0.013	0.010	0.017
	Avg	**-0.003**	**-0.009**	**0.028**	**0.010**	**0.011**	**0.016**
	Stdev	**0.001**	**0.021**	**0.014**	**0.004**	**0.001**	**0.004**
FTP-wo	1	0.014	-0.005	-0.020	0.007	-0.005	0.017
	2	-0.011	-0.024	-0.004	-0.004	-0.005	-0.005
	3	-0.009	-0.020	-0.011	-0.011	-0.008	-0.005
	Avg	**-0.002**	**-0.016**	**-0.012**	**-0.003**	**-0.006**	**0.002**
	Stdev	**0.014**	**0.010**	**0.008**	**0.009**	**0.001**	**0.012**
CARBx-ICT	1	0.392	0.103	N/A	0.375	CARBx-ICT, CARBz-CH, and the 16-Hour cycle were not run with this engine	
	2	0.417	0.181	N/A	0.305		
	Avg	**0.405**	**0.142**	**N/A**	**0.340**		
	Stdev	**0.017**	**0.055**	**N/A**	**0.049**		
CARBz-CH	1	0.003	-0.001	N/A	0.012		
	2	-0.001	-0.004	N/A	0.012		
	Avg	**0.001**	**-0.002**	**N/A**	**0.012**		
	Stdev	**0.003**	**0.002**	**N/A**	**0.000**		
16-Hour	1	0.000	-0.021	0.003	0.000		
	2	-0.002	-0.002	-0.024	0.002		
	3	-0.001	-0.017	0.000	-0.005		
	Avg	**-0.001**	**-0.013**	**-0.007**	**-0.001**		
	Stdev	**0.001**	**0.010**	**0.015**	**0.003**		



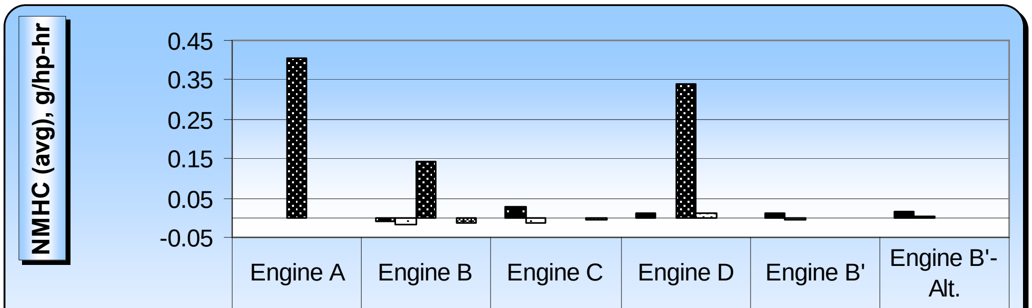
	Engine A	Engine B	Engine C	Engine D	Engine B'	Engine B'-Alt.
FTP-w	0.006	0.016	0.042	0.018	0.029	0.025
FTP-wo	0.003	-0.002	-0.002	0.005	0.008	0.008
CARBx-ICT	0.465	0.165	N/A	0.388	Not Run	
CARBz-CH	0.008	0.004		0.018		
16-Hour	0.004	0.004	0.005	0.007		

FIGURE 27. AVERAGE BRAKE-SPECIFIC THC EMISSIONS



	Engine A	Engine B	Engine C	Engine D	Engine B'	Engine B'-Alt.
FTP-w	0.009	0.025	0.014	0.009	0.020	0.010
FTP-wo	0.005	0.014	0.010	0.008	0.015	0.007
CARBx-ICT	0.060	0.023	N/A	0.048	Not Run	
CARBz-CH	0.007	0.007		0.006		
16-Hour	0.005	0.017	0.012	0.007		

FIGURE 28. AVERAGE BRAKE-SPECIFIC CH_4 EMISSIONS



	Engine A	Engine B	Engine C	Engine D	Engine B'	Engine B'-Alt.
FTP-w	-0.003	-0.009	0.028	0.010	0.011	0.016
FTP-wo	-0.002	-0.016	-0.012	-0.003	-0.006	0.002
CARBx-ICT	0.405	0.142	N/A	0.340	Not Run	
CARBz-CH	0.001	-0.002		0.012		
16-Hour	-0.001	-0.013	-0.007	-0.001		

FIGURE 29. AVERAGE BRAKE-SPECIFIC NMHC EMISSIONS

5.6 Carbon Dioxide Emissions and BSFC

CO_2 is becoming increasingly important because it is a major greenhouse gas. In the case of diesel engines, it is also indicative of fuel consumption. Table 21 and Figure 30 show the brake-specific CO_2 emissions, and Table 22 and Figure 31 show the brake-specific fuel consumption (BSFC), which is calculated based on emissions. CO_2 ranged from 547 g/hp-hr for Engine D, CARBz-CH, to 941 g/hp-hr for Engine A, CARBx-ICT. Generally, the lightest loaded cycle, CARBx-ICT, resulted in the highest $BSCO_2$ and BSFC, and the highest loaded cycle, CARBz-CH, resulted in the lowest $BSCO_2$ and BSFC.

5.7 Particulate Matter Emissions

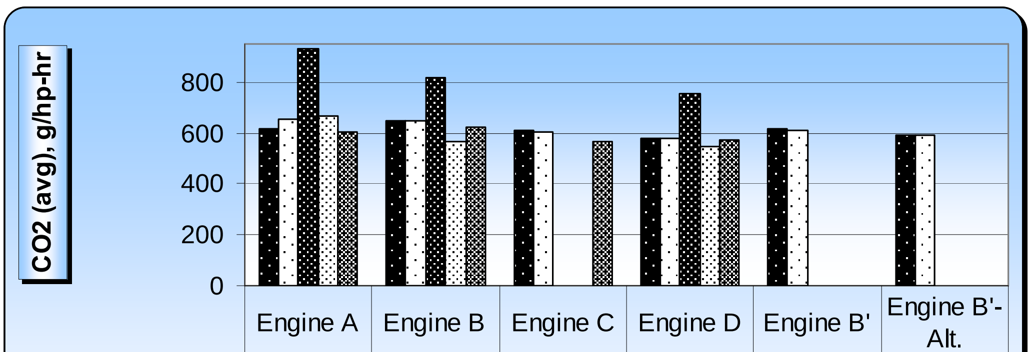
Several metrics and methods were used to characterize PM. This section includes information on Teflon® membrane filter-based PM measurement, quartz filter-based OC/EC analysis, filter-based elemental EDXRF analysis, real time total PM using the DMM-230, real time soot using the MSS, and real time number and size using the EEPS.

5.7.1 Filter-Based PM Mass-CVS Tunnel and Exposure Chamber

Filter-based PM was collected from two locations. The first was the CVS tunnel sample zone, in accordance with CFR Part 1065, where the filter face temperature was maintained at 47°C ± 5°C, and total residence time (CVS plus secondary tunnel) was on the order of 3 seconds. The second location was the exposure chamber, where the dilution ratio from the CVS was about 2, the filter face temperature was about 28°C, and the residence time was on the order of 4 to 5 minutes to purge 90 percent of the volume entering the chamber. It takes an additional 15 minutes for the remaining 10 percent to be fully purged. The temperature of the exposure chamber filter was not actively controlled and was dictated by the temperature inside the exposure chamber. The total flow through each of the 47 mm filters was approximately 57 slpm, resulting in a filter face velocity near 100 cm/s. Table 23 and Figure 32, and Table 24 and Figure 33 show the brake-specific PM emissions from the CVS and the exposure chamber, respectively. Generally, PM emissions were very low, well below the 2007 PM standard of 0.01 g/hp-hr for the FTP.

TABLE 21. BRAKE-SPECIFIC CO_2 EMISSIONS

Test Cycle	Test Number	CO_2, g/hp-hr					
		SwRI Elevation					Lovelace Elevation
		Engine A	Engine B	Engine C	Engine D	Engine B'	Engine B'-Alt.
FTP-w	1	619	647	605	580	616	589
	2	620	650	613	575	616	590
	3	619	644	609	579	614	591
	Avg	**619**	**647**	**609**	**578**	**615**	**590**
	Stdev	**0**	**3**	**4**	**3**	**1**	**1**
	COV	**0.1%**	**0.4%**	**0.6%**	**0.5%**	**0.2%**	**0.1%**
FTP-wo	1	660	648	606	577	613	591
	2	650	649	604	576	613	597
	3	648	649	606	576	613	589
	Avg	**653**	**649**	**605**	**576**	**613**	**592**
	Stdev	**6**	**1**	**1**	**1**	**0**	**5**
	COV	**1.0%**	**0.1%**	**0.2%**	**0.1%**	**0.0%**	**0.8%**
CARBx-ICT	1	941	819	N/A	754	CARBx-ICT, CARBz-CH, and the 16-Hour cycle were not run with this engine	
	2	926	813	N/A	755		
	Avg	**934**	**816**	**N/A**	**754**		
	Stdev	**10**	**4**	**N/A**	**1**		
	COV	**1.1%**	**0.5%**	**N/A**	**0.1%**		
CARBz-CH	1	662	563	N/A	547		
	2	669	568	N/A	550		
	Avg	**665**	**565**	**N/A**	**549**		
	Stdev	**5**	**3**	**N/A**	**2**		
	COV	**0.8%**	**0.6%**	**N/A**	**0.3%**		
16-Hour	1	597	615	567	576		
	2	604	620	565	574		
	3	602	624	564	573		
	Avg	**601**	**620**	**565**	**574**		
	Stdev	**4**	**4**	**2**	**2**		
	COV	**0.6%**	**0.7%**	**0.3%**	**0.3%**		



	Engine A	Engine B	Engine C	Engine D	Engine B'	Engine B'-Alt.
FTP-w	619	647	609	578	615	590
FTP-wo	653	649	605	576	613	592
CARBx-ICT	934	816	N/A	754	Not Run	
CARBz-CH	665	565		549		
16-Hour	601	620	565	574		

FIGURE 30. AVERAGE BRAKE-SPECIFIC CO_2 EMISSIONS

TABLE 22. BRAKE-SPECIFIC FUEL CONSUMPTION

Test Cycle	Test Number	BSFC, lb/hp-hr					
		SwRI Elevation					Lovelace Elevation
		Engine A	Engine B	Engine C	Engine D	Engine B'	Engine B'-Alt.
FTP-w	1	0.466	0.447	0.419	0.401	0.427	0.409
	2	0.428	0.449	0.423	0.397	0.427	0.409
	3	0.428	0.445	0.421	0.400	0.426	0.409
	Avg	**0.441**	**0.447**	**0.421**	**0.399**	**0.426**	**0.409**
	Stdev	**0.022**	**0.002**	**0.002**	**0.002**	**0.001**	**0.000**
	COV	**5.0%**	**0.5%**	**0.5%**	**0.5%**	**0.2%**	**0.1%**
FTP-wo	1	0.456	0.447	0.419	0.399	0.425	0.409
	2	0.449	0.448	0.417	0.398	0.425	0.414
	3	0.448	0.448	0.419	0.398	0.425	0.408
	Avg	**0.451**	**0.448**	**0.418**	**0.398**	**0.425**	**0.410**
	Stdev	**0.004**	**0.000**	**0.001**	**0.000**	**0.000**	**0.003**
	COV	**1.0%**	**0.1%**	**0.2%**	**0.1%**	**0.0%**	**0.8%**
CARBx-ICT	1	0.654	0.566	N/A	0.524	CARBx-ICT, CARBz-CH, and the 16-Hour cycle were not run with this engine	
	2	0.643	0.563	N/A	0.524		
	Avg	**0.649**	**0.564**	**N/A**	**0.524**		
	Stdev	**0.007**	**0.002**	**N/A**	**0.000**		
	COV	**1.1%**	**0.4%**	**N/A**	**0.1%**		
CARBz-CH	1	0.457	0.389	N/A	0.378		
	2	0.462	0.393	N/A	0.380		
	Avg	**0.460**	**0.391**	**N/A**	**0.379**		
	Stdev	**0.004**	**0.002**	**N/A**	**0.001**		
	COV	**0.8%**	**0.6%**	**N/A**	**0.3%**		
16-Hour	1	0.413	0.425	0.392	0.398		
	2	0.418	0.429	0.391	0.397		
	3	0.416	0.431	0.390	0.396		
	Avg	**0.416**	**0.428**	**0.391**	**0.397**		
	Stdev	**0.002**	**0.003**	**0.001**	**0.001**		
	COV	**0.5%**	**0.7%**	**0.3%**	**0.3%**		

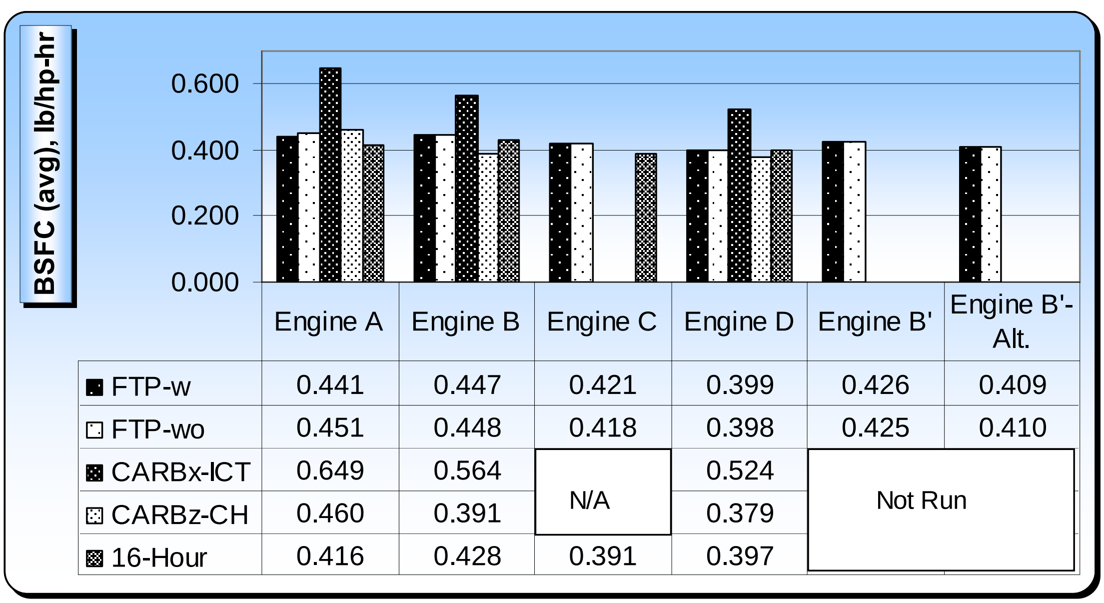
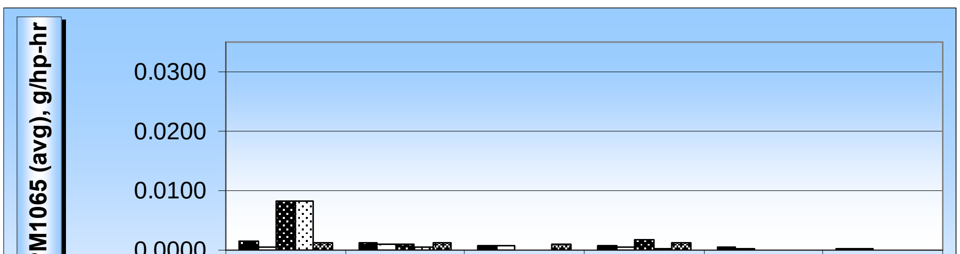


FIGURE 31. AVERAGE BRAKE-SPECIFIC FUEL CONSUMPTION

TABLE 23. BRAKE-SPECIFIC PM EMISSIONS (CVS TUNNEL, CFR PART 1065)

Test Cycle	Test Number	PM (Part 1065), g/hp-hr SwRI Elevation Engine A	Engine B	Engine C	Engine D	Engine B'	Lovelace Elevation Engine B'
FTP-w	1	0.0015	0.0013	0.0009	0.0005	0.0005	0.0004
	2	0.0013	0.0018	0.0005	0.0011	0.0003	0.0002
	3	0.0019	0.0008	0.0009	0.0007	0.0004	0.0001
	Avg	**0.0016**	**0.0013**	**0.0008**	**0.0008**	**0.0004**	**0.0002**
	Stdev	**0.0003**	**0.0005**	**0.0002**	**0.0003**	**0.0001**	**0.0001**
	COV	**17.0%**	**37.4%**	**31.7%**	**39.8%**	**23.0%**	**54.0%**
FTP-wo	1	0.0004	0.0004	0.0007	0.0008	0.0004	0.0001
	2	0.0010	0.0012	0.0008	0.0002	-0.0001	0.0005
	3	0.0003	0.0011	0.0006	0.0005	0.0002	0.0001
	Avg	**0.0006**	**0.0009**	**0.0007**	**0.0005**	**0.0002**	**0.0003**
	Stdev	**0.0004**	**0.0004**	**0.0001**	**0.0003**	**0.0002**	**0.0002**
	COV	**63.9%**	**45.6%**	**15.2%**	**54.3%**	**132.3%**	**78.1%**
CARBx-ICT	1	0.0074	0.0013	NA	0.0022	CARBx-ICT, CARBz-CH, and the 16-Hour cycle were not run with this engine	
	2	0.0092	0.0005	NA	0.0014		
	Avg	**0.0083**	**0.0009**	**NA**	**0.0018**		
	Stdev	**0.0013**	**0.0006**	**NA**	**0.0005**		
	COV	**16.2%**	**66.0%**	**NA**	**30.3%**		
CARBz-CH	1	0.0046	0.0007	NA	0.0003		
	2	0.0117	0.0006	NA	0.0002		
	Avg	**0.0082**	**0.0006**	**NA**	**0.0003**		
	Stdev	**0.0050**	**0.0001**	**NA**	**0.0001**		
	COV	**61.8%**	**12.8%**	**NA**	**24.0%**		
16-Hour	1	0.0003	0.0015	0.0017	0.0016		
	2	0.0019	0.0009	0.0012	0.0008		
	3	0.0016	0.0012	0.0004	0.0014		
	Avg	**0.0013**	**0.0012**	**0.0011**	**0.0013**		
	Stdev	**0.0009**	**0.0003**	**0.0006**	**0.0004**		
	COV	**67.8%**	**26.1%**	**58.4%**	**31.0%**		



	Engine A	Engine B	Engine C	Engine D	Engine B'	Engine B'-Alt.
FTP-w	0.0016	0.0013	0.0008	0.0008	0.0004	0.0002
FTP-wo	0.0006	0.0009	0.0007	0.0005	0.0002	0.0003
CARBx-ICT	0.0083	0.0009	N/A	0.0018	Not Run	
CARBz-CH	0.0082	0.0006		0.0003		
16-Hour	0.0013	0.0012	0.0011	0.0013		

FIGURE 32. AVERAGE BRAKE-SPECIFIC PM EMISSIONS (CVS TUNNEL, CFR PART 1065)

TABLE 24. BRAKE-SPECIFIC PM EMISSIONS (EXPOSURE CHAMBER)

Test Cycle	Test Number	PM (Exp. Chamber), g/hp-hr			
		Engine A	Engine B	Engine C	Engine D
FTP-w	1	0.0018	0.0024	0.0003	0.0009
	2	0.0013	0.0013	0.0001	0.0009
	3	-	0.0007	0.0005	0.0009
	Avg	**0.0015**	**0.0015**	**0.0003**	**0.0009**
	Stdev	**0.0003**	**0.0009**	**0.0002**	**0.0000**
	COV	**20.7%**	**59.9%**	**57.0%**	**0.6%**
FTP-wo	1	0.0007	0.0006	0.0000	0.0006
	2	0.0008	0.0009	0.0007	0.0007
	3	0.0018	0.0007	0.0006	0.0003
	Avg	**0.0011**	**0.0007**	**0.0004**	**0.0005**
	Stdev	**0.0006**	**0.0001**	**0.0003**	**0.0002**
	COV	**58.0%**	**16.9%**	**82.5%**	**39.1%**
CARBx-ICT	1	0.0085	0.0010	N/A	-0.0036
	2	0.0073	0.0013	N/A	0.0015
	Avg	**0.0079**	**0.0011**	**N/A**	**0.0015**
	Stdev	**0.0008**	**0.0002**	**N/A**	**-**
	COV	**10.2%**	**21.3%**	**N/A**	**-**
CARBz-CH	1	0.0083	0.0008	N/A	0.0004
	2	0.0203	0.0007	N/A	0.0004
	Avg	**0.0143**	**0.0007**	**N/A**	**0.0004**
	Stdev	**0.0085**	**0.0001**	**N/A**	**0.0000**
	COV	**59.1%**	**8.6%**	**N/A**	**9.8%**
16-Hour	1	0.0005	0.0033	0.0020	0.0026
	2	0.0042	0.0022	0.0017	0.0015
	3	0.0042	0.0028	0.0005	0.0017
	Avg	**0.0030**	**0.0028**	**0.0014**	**0.0019**
	Stdev	**0.0021**	**0.0005**	**0.0008**	**0.0005**
	COV	**71.5%**	**19.2%**	**56.2%**	**28.0%**

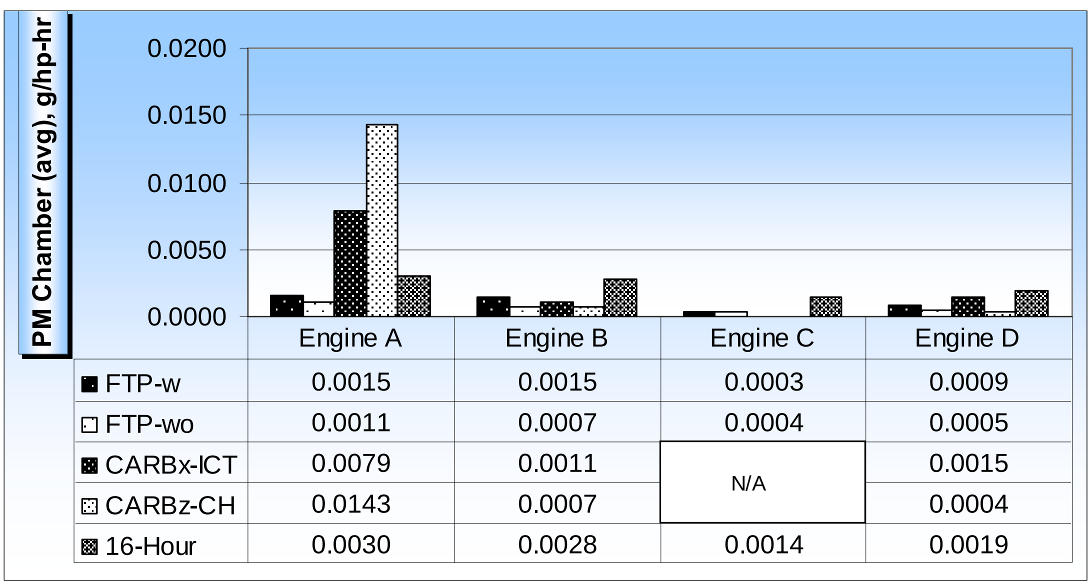


FIGURE 33. AVERAGE BRAKE-SPECIFIC PM EMISSIONS (EXPOSURE CHAMBER)

Figure 34 shows the ratio of PM with blow-by and PM without blow-by for the FTP. On average, across all engines, the PM with blow-by was about 50 percent higher based on both the CVS and exposure chamber PM results.

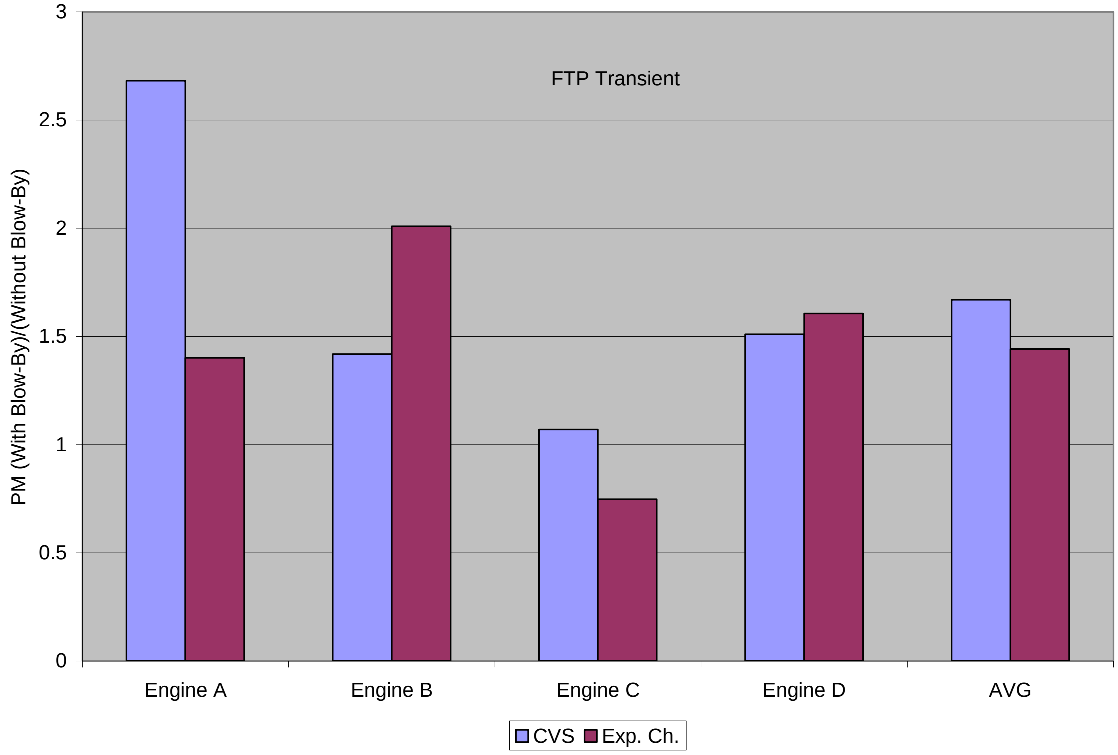


FIGURE 34. RATIO OF PM WITH BLOW-BY AND PM WITHOUT BLOW-BY

Figure 35 shows the ratio of exposure chamber-based PM and CVS-based PM. For the FTP and CARBx-ICT (light load cycles), there were no notable differences in PM between the two sampling locations. For the CARBz-CH and the 16-Hour cycle, the exposure chamber result was 50 to 100 percent higher, respectively, for these cycles. It is important to note that the 16-Hour cycle filter-based PM measurement should be considered the most precise due to the high level of PM accumulated on the sample filter. While the PM collected on an FTP sample filter was on the order of 10 μg, the 16-Hour cycle filter typically had more than 500 μg.

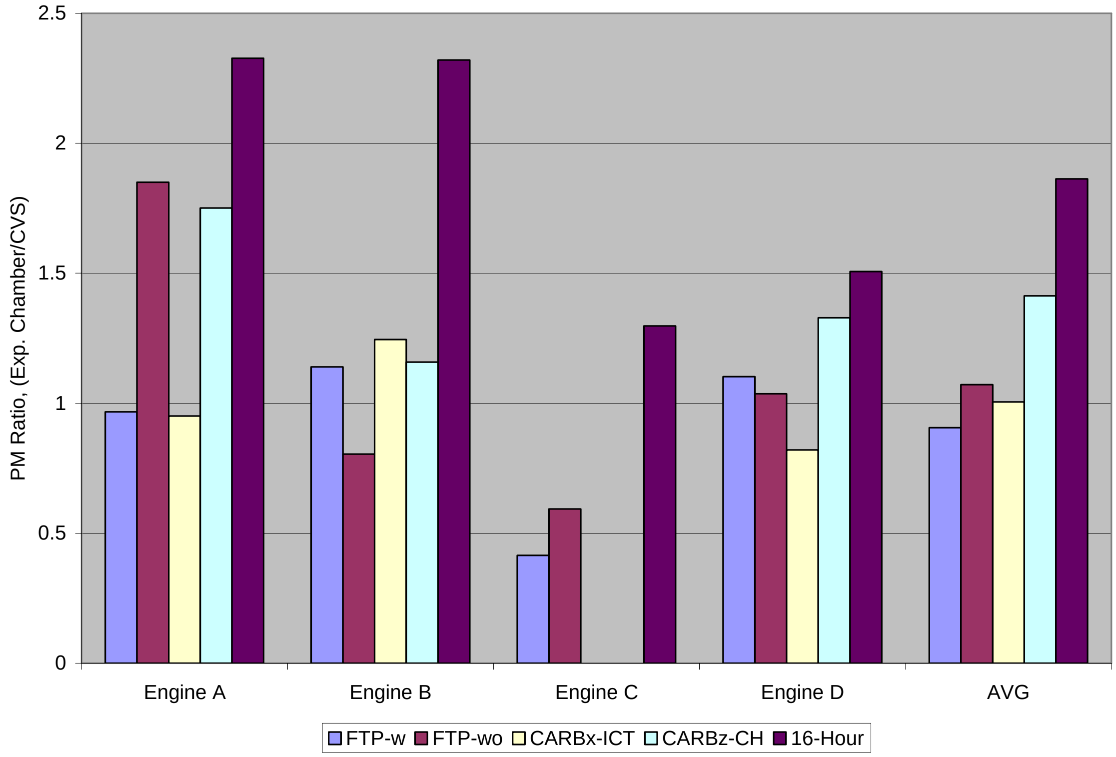


FIGURE 35. RATIO OF PM BASED ON EXPOSURE CHAMBER AND PM BASED ON CVS USING CFR PART 1065

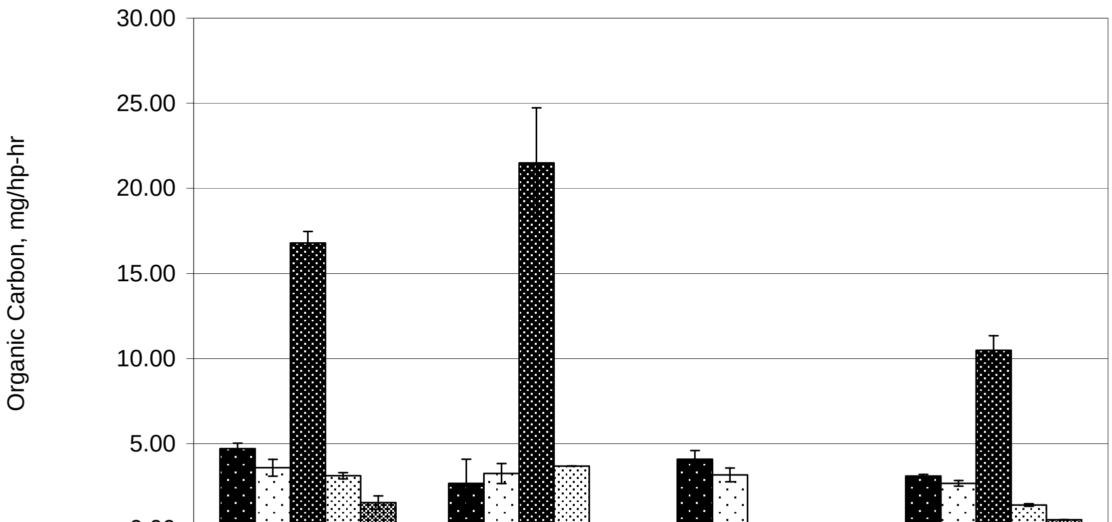
5.7.2 Quartz Filter-Based OC/EC-Exposure Chamber

PM was collected on quartz filters from the exposure chamber, and the filters were analyzed using the OC/EC reflectance method by DRI. Table 25, and Figures 36 and 37 show the average brake-specific OC/EC emissions. The 16-Hour cycle data are considered the most precise due to the long sampling time, where a larger PM quantity was collected on the filter. For the 16-Hour cycle, with the exception of OC for engine A, which was about 7 times higher than the mass of EC, the OC emissions were similar to EC with Engine B and C, and over twice the EC for Engine D. For the FTP, the EC represented less than 3 percent of the 2007 PM standard. The OC was comparable to tunnel blank levels, and it was on the order of 40 percent of the 2007 PM standard, perhaps due to positive gas phase artifact collection by the quartz filter material.

Based on all engines tested, the average EC to OC ratio was 4.1 percent for the FTP-w (with blow-by), 3.2 percent for the FTP-wo (without blow-by), 1.6 percent for CARBx-ICT, 12.1 percent for CARBz-CH, 37.3 percent for the 16-Hour cycle, and 3.6 percent for TB (tunnel blank). In principle, the longer the cycle the higher the EC to OC ratio, suggesting that with longer cycles, the accumulation of OC on the filter is decreasing as function of time due to perhaps the positive gas phase artifact reaching equilibrium with the filter media.

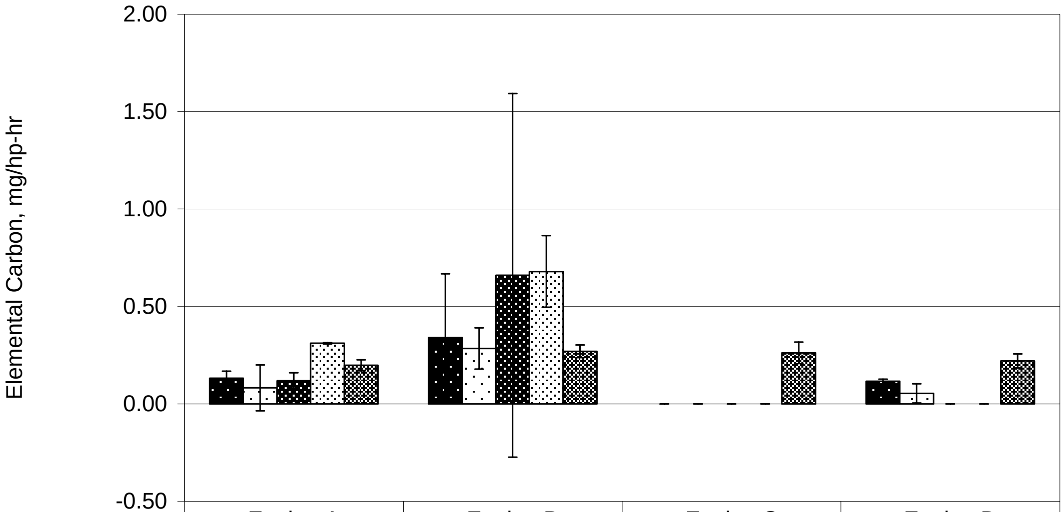
TABLE 25. AVERAGE BRAKE-SPECIFIC ELEMENTAL/ORGANIC CARBON EMISSIONS BASED ON FILTER COLLECTION FROM EXPOSURE CHAMBER

Test Cycle	Number of Repeats		Elemental/Organic Carbon, mg/hp-hr							
			Engine A		Engine B		Engine C		Engine D	
			EC	OC	EC	OC	EC	OC	EC	OC
FTP-w	3	**Avg**	0.13	4.70	0.34	2.67	0.00	4.08	0.12	3.10
		Stdev	0.04	0.32	0.33	1.41	0.00	0.52	0.01	0.09
		COV	27%	7%	97%	53%	0%	13%	9%	3%
FTP-wo	3	**Avg**	0.08	3.58	0.28	3.24	0.00	3.16	0.05	2.67
		Stdev	0.12	0.50	0.11	0.59	0.00	0.41	0.05	0.17
		COV	144%	14%	37%	18%	0%	13%	91%	6%
CARBx-ICT	2	**Avg**	0.12	16.79	0.66	21.49	N/A	N/A	0.00	10.48
		Stdev	0.04	0.68	0.93	3.24	N/A	N/A	0.00	0.87
		COV	34%	4%	141%	15%	N/A	N/A	0%	8%
CARBz-CH	2	**Avg**	0.31	3.11	0.68	3.68	N/A	N/A	0.00	1.39
		Stdev	0.00	0.19	0.18	0.01	N/A	N/A	0.00	0.07
		COV	0.0	0.1	0.3	0.0	N/A	N/A	0.0	0.1
16 Hour	3	**Avg**	0.20	1.53	0.27	0.24	0.26	0.26	0.22	0.52
		Stdev	0.03	0.40	0.03	0.04	0.06	0.02	0.04	0.01
		COV	14%	26%	12%	15%	21%	7%	16%	2%
TB	3	**Avg**	0.00	0.05	0.28	3.24	0.00	3.16	0.05	2.67
		Stdev	0.00	0.01	0.11	0.59	0.00	0.41	0.05	0.17
		COV	130%	13%	37%	18%	0%	13%	91%	6%



	Engine A	Engine B	Engine C	Engine D
FTP-w	4.70	2.67	4.08	3.10
FTP-wo	3.58	3.24	3.16	2.67
CARBx-ICT	16.79	21.49	N/A	10.48
CARBz-CH	3.11	3.68		1.39
16 Hour	1.53	0.24	0.26	0.52

FIGURE 36. AVERAGE ORGANIC CARBON EMISSIONS BASED ON FILTER COLLECTION FROM EXPOSURE CHAMBER



	Engine A	Engine B	Engine C	Engine D
FTP-w	0.13	0.34	0.00	0.12
FTP-wo	0.08	0.28	0.00	0.05
CARBx-ICT	0.12	0.66	N/A	0.00
CARBz-CH	0.31	0.68		0.00
16 Hour	0.20	0.27	0.26	0.22

FIGURE 37. AVERAGE ELEMENTAL CARBON EMISSIONS BASED ON FILTER COLLECTION FROM EXPOSURE CHAMBER

5.7.3 DMM-Based Total PM Mass-Exposure Chamber

Table 26 and Figure 38 summarize the DMM-based PM emissions for all engines and cycles tested. The DMM was very sensitive to regeneration events, particularly during the 16-Hour cycle, and also for the regeneration that occurred during CARBz-CH for Engine A.

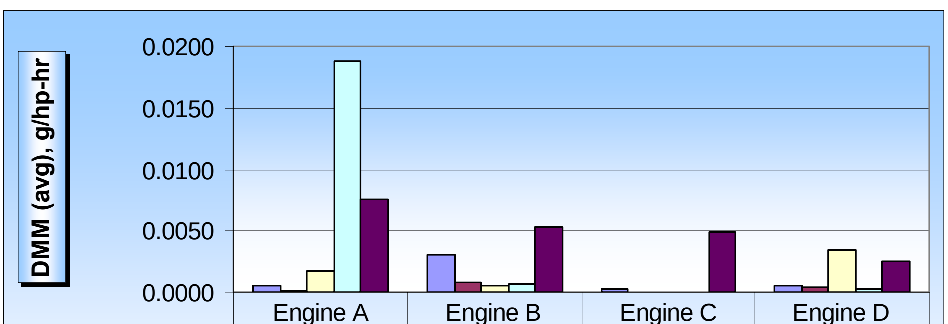
Overall, the DMM gave higher PM mass emissions than that reported using the filter-based method, particularly when regeneration events occurred. This may be due to the high number of small particles generated during the active regeneration event, some of which may have diffused to the upper stages of the DMM, giving an apparent higher PM result.

5.7.4 MSS-Based Soot Mass-Exposure Chamber

Table 27 and Figure 39 summarize the soot emission results measured by the MSS. The soot concentration in the exposure chamber was very low -- on the order of 8 $\mu g/m^3$, which is close to the detection limit of the MSS (~5 µg/m). Since the elemental carbon concentration was so low, the MSS measured directly from the exposure chamber without any addition of dilution air from its conditioning unit. For the FTP, the soot emissions were very low -- on the order of one percent of the total PM.

TABLE 26. DMM-BASED BRAKE-SPECIFIC PM MASS EMISSIONS - EXPOSURE CHAMBER

Test Cycle	Test Number	DMM-Mass, g/hp-hr			
		Engine A	Engine B	Engine C	Engine D
FTP-w	1	0.0005	0.0070	0.0003	0.0007
	2	0.0005	0.0011	0.0002	0.0007
	3	0.0005	0.0010	0.0002	0.0000
	Avg	**0.0005**	**0.0030**	**0.0002**	**0.0005**
	Stdev	**0.0000**	**0.0035**	**0.0001**	**0.0004**
	COV	**0.8%**	**114.0%**	**29.4%**	**86.9%**
FTP-wo	1	0.0000	0.0009	0.0002	0.0004
	2	0.0001	0.0008	0.0000	0.0004
	3	0.0002	0.0007	0.0000	0.0004
	Avg	**0.0001**	**0.0008**	**0.0001**	**0.0004**
	Stdev	**0.0001**	**0.0001**	**0.0001**	**0.0000**
	COV	**96.1%**	**7.9%**	**173.2%**	**7.7%**
CARBx-ICT	1	0.0016	0.0006	N/A	0.0060
	2	0.0019	0.0006	N/A	0.0008
	Avg	**0.0017**	**0.0006**	N/A	**0.0034**
	Stdev	**0.0002**	**0.0000**	N/A	**0.0037**
	COV	**12.9%**	**0.3%**	N/A	**108.1%**
CARBz-CH	1	0.0019	0.0007	N/A	0.0003
	2	0.0357	0.0007	N/A	0.0003
	Avg	**0.0188**	**0.0007**	N/A	**0.0003**
	Stdev	**0.0239**	**0.0000**	N/A	**0.0000**
	COV	**127.3%**	**4.9%**	N/A	**1.9%**
16-Hour	1	0.0062	0.0033	0.0034	0.0044
	2	0.0055	0.0059	0.0034	0.0006
	3	0.0112	0.0066	0.0008	0.0027
	Avg	**0.0076**	**0.0053**	**0.0049**	**0.0026**
	Stdev	**0.0031**	**0.0017**	**0.0064**	**0.0019**
	COV	**41.0%**	**32.4%**	**130.1%**	**75.0%**

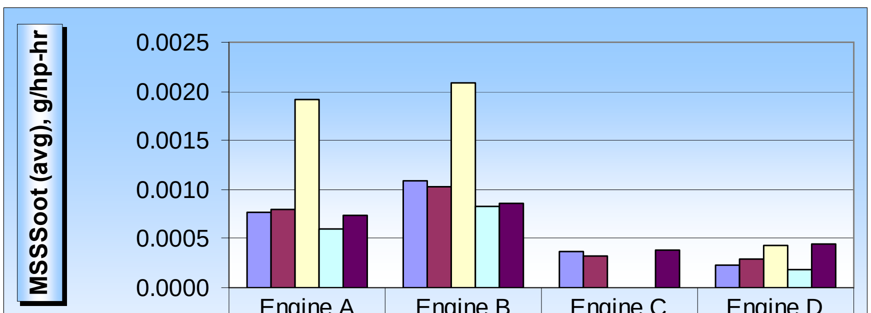


	Engine A	Engine B	Engine C	Engine D
FTP-w	0.0005	0.0030	0.0002	0.0005
FTP-wo	0.0001	0.0008	0.0001	0.0004
CARBx-ICT	0.0017	0.0006	N/A	0.0034
CARBz-CH	0.0188	0.0007	N/A	0.0003
16-Hour	0.0076	0.0053	0.0049	0.0026

FIGURE 38. AVERAGE DMM-BASED BRAKE-SPECIFIC PM MASS EMISSIONS - EXPOSURE CHAMBER

TABLE 27. MSS-BASED BRAKE-SPECIFIC SOOT MASS EMISSIONS - EXPOSURE CHAMBER

Test Cycle	Test Number	MSS-Soot, g/hp-hr			
		Engine A	Engine B	Engine C	Engine D
FTP-w	1	0.0008	0.0013	0.0004	0.0004
	2	0.0008	0.0011	0.0003	0.0003
	3	-	0.0009	0.0003	0.0000
	Avg	**0.0008**	**0.0011**	**0.0004**	**0.0002**
	Stdev	**0.0000**	**0.0002**	**0.0001**	**0.0002**
	COV	**1.6%**	**17.1%**	**15.8%**	**86.9%**
FTP-wo	1	0.0008	0.0010	0.0004	0.0003
	2	0.0008	0.0010	0.0003	0.0003
	3	0.0008	0.0011	0.0003	0.0003
	Avg	**0.0008**	**0.0010**	**0.0003**	**0.0003**
	Stdev	**0.0000**	**0.0001**	**0.0000**	**0.0000**
	COV	**3.0%**	**5.7%**	**11.7%**	**9.1%**
CARBx-ICT	1	-	0.0021	N/A	0.0006
	2	0.0019	0.0021	N/A	0.0003
	Avg	**0.0019**	**0.0021**	N/A	**0.0004**
	Stdev	**-**	**0.0000**	N/A	**0.0002**
	COV	**-**	**0.1%**	N/A	**56.8%**
CARBz-CH	1	0.0005	0.0008	N/A	0.0002
	2	0.0006	0.0009	N/A	0.0002
	Avg	**0.0006**	**0.0008**	N/A	**0.0002**
	Stdev	**0.0001**	**0.0001**	N/A	**0.0000**
	COV	**12.0%**	**7.3%**	N/A	**11.7%**
16-Hour	1	0.0008	0.0010	0.0005	0.0005
	2	0.0007	0.0007	0.0005	0.0002
	3	0.0007	0.0009	0.0004	0.0006
	Avg	**0.0007**	**0.0009**	**0.0004**	**0.0004**
	Stdev	**0.0000**	**0.0001**	**0.0000**	**0.0002**
	COV	**3.8%**	**14.6%**	**8.9%**	**42.2%**



	Engine A	Engine B	Engine C	Engine D
FTP-w	0.0008	0.0011	0.0004	0.0002
FTP-wo	0.0008	0.0010	0.0003	0.0003
CARBx-ICT	0.0019	0.0021	N/A	0.0004
CARBz-CH	0.0006	0.0008		0.0002
16-Hour	0.0007	0.0009	0.0004	0.0004

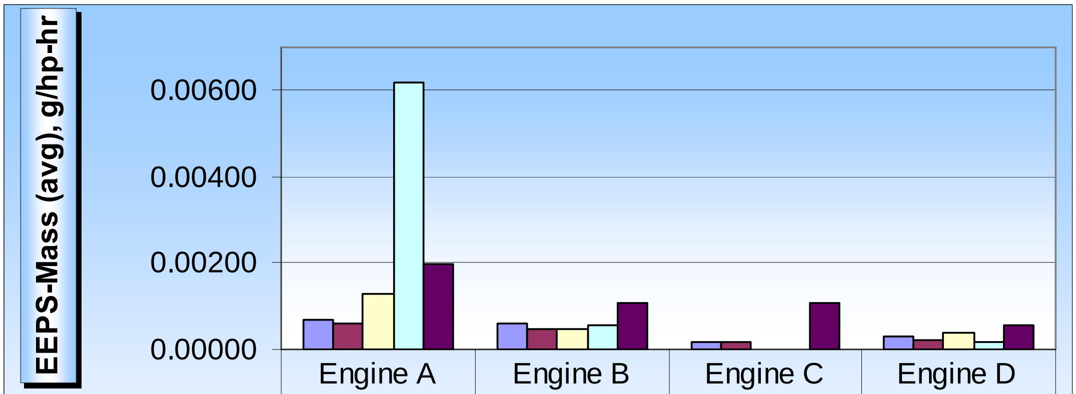
FIGURE 39. AVERAGE MSS-BASED BRAKE-SPECIFIC SOOT MASS EMISSIONS - EXPOSURE CHAMBER

5.7.5 EEPS-Based Particle Mass-Exposure Chamber

Table 28 and Figure 40 show the EEPS-based PM mass emissions from the exposure chamber. PM mass was calculated assuming spherical particles with a density of 1 g/cm³. The EEPS-based mass emissions were generally on the order of 20 to 75 percent of the PM emissions reported using the exposure chamber filter method.

TABLE 28. EEPS-BASED BRAKE-SPECIFIC PM MASS EMISSIONS - EXPOSURE CHAMBER

Test Cycle		EEPS-Mass, g/hp-hr			
		Engine A	**Engine B**	**Engine C**	**Engine D**
FTP-w	1	0.00070	0.00084	0.00019	0.00028
	2	0.00069	0.00056	0.00023	0.00030
	3	0.00069	0.00045	0.00015	0.00028
	Avg	**0.00069**	**0.00062**	**0.00019**	**0.00028**
	Stdev	**0.0000**	**0.0002**	**0.0000**	**0.0000**
	COV	**0.5%**	**32.4%**	**21.5%**	**4.0%**
FTP-wo	1	0.00020	0.00049	0.00019	0.00018
	2	-	0.00045	0.00011	0.00021
	3	0.00096	0.00054	0.00018	0.00020
	Avg	**0.00058**	**0.00049**	**0.00016**	**0.00020**
	Stdev	**0.0005**	**0.0000**	**0.0000**	**0.0000**
	COV	**93.0%**	**8.8%**	**26.2%**	**9.0%**
CARBx-ICT	1	0.00142	0.00046	N/A	0.00054
	2	0.00120	0.00046	N/A	0.00023
	Avg	**0.00131**	**0.00046**	N/A	**0.00039**
	Stdev	**0.0002**	**0.0000**	N/A	**0.0002**
	COV	**11.9%**	**0.2%**	N/A	**56.8%**
CARBz-CH	1	0.00371	0.00068	N/A	0.00016
	2	0.00867	0.00041	N/A	0.00018
	Avg	**0.00619**	**0.00055**	N/A	**0.00017**
	Stdev	**0.0035**	**0.0002**	N/A	**0.0000**
	COV	**56.7%**	**34.9%**	N/A	**9.0%**
16-Hour	1	0.00204	0.00096	0.00087	0.00079
	2	0.00184	0.00109	0.00078	0.00024
	3	0.00205	0.00113	0.00033	0.00061
	Avg	**0.00198**	**0.00106**	**0.00066**	**0.00054**
	Stdev	**0.0001**	**0.0001**	**0.00030**	**0.0003**
	COV	**6.0%**	**8.2%**	**44.3%**	**51.2%**



	Engine A	Engine B	Engine C	Engine D
FTP-w	0.00069	0.00062	0.00019	0.00028
FTP-wo	0.00058	0.00049	0.00016	0.00020
CARBx-ICT	0.00131	0.00046	N/A	0.00039
CARBz-CH	0.00619	0.00055	N/A	0.00017
16-Hour	0.00198	0.00106	0.00106	0.00054

FIGURE 40. AVERAGE EEPS-BASED PM MASS EMISSIONS - EXPOSURE CHAMBER

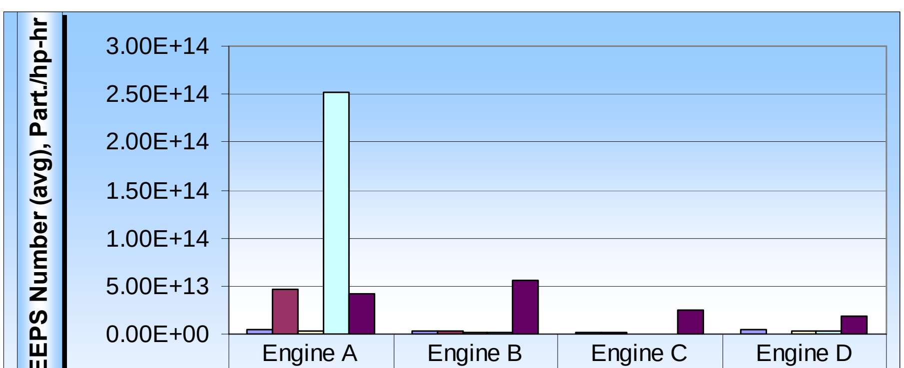
5.7.6 EEPS-Based Particle Number-Exposure Chamber

Table 29 and Figure 41 summarize the data on brake-specific PM number emissions in the exposure chamber. Particle number emissions were extremely sensitive to regeneration events. For Engine A, FTP-wo, where active regeneration events took place during a small portion of the cycle, the average particle number emissions was at least one order of magnitude higher than the average reported for the FTP-w, where no regeneration events occurred. The same thing can be said for Engine A, CARBz-CH, compared to the other ACES engines. For the 16-Hour cycle, the average particle number emission level was at least one order of magnitude higher than the FTP cycle because of the regeneration events that occurred during a fraction of the 16-Hour cycle. These ranged from less than 30 minutes to a few hours, depending on each engine manufacturer's regeneration strategy. Since the elemental carbon measured by the OC/EC method and the soot measured by the MSS remained low even during active regeneration, one can hypothesize that the majority of particle number emissions are volatile PM.

The effect of blow-by can also be seen with particle number measurement during the FTP transient runs, particularly for Engine C and D, where the average particle number emissions with blow-by were a factor of 2 to 7 higher than those without blow-by. Engine B showed a small increase -- on the order of 37 percent. For Engine A, no active regeneration took place for the without blow-by case, so no such comparison was made.

TABLE 29. EEPS-BASED BRAKE-SPECIFIC PM NUMBER EMISSIONS - EXPOSURE CHAMBER

Test Cycle	Test Number	Particle Number, part./hp-hr			
		Engine A	Engine B	Engine C	Engine D
FTP-w	1	4.48E+12	5.11E+12	1.83E+12	5.12E+12
	2	4.78E+12	3.26E+12	4.26E+12	5.02E+12
	3	5.16E+12	2.63E+12	6.81E+11	4.86E+12
	Avg	**4.81E+12**	**3.67E+12**	**2.26E+12**	**5.00E+12**
	Stdev	**3.41E+11**	**1.29E+12**	**1.83E+12**	**1.31E+11**
	COV	**7.1%**	**35.1%**	**81.0%**	**2.6%**
FTP-wo	1	4.52E+13	2.78E+12	6.09E+11	6.51E+11
	2	-	2.58E+12	5.66E+11	7.10E+11
	3	4.75E+13	2.63E+12	1.72E+12	7.16E+11
	Avg	**4.64E+13**	**2.66E+12**	**9.65E+11**	**6.92E+11**
	Stdev	**1.63E+12**	**1.06E+11**	**6.53E+11**	**3.58E+10**
	COV	**3.5%**	**4.0%**	**67.7%**	**5.2%**
CARBx-ICT	1	2.90E+12	2.14E+12	N/A	4.16E+12
	2	3.40E+12	2.15E+12	N/A	1.91E+12
	Avg	**3.15E+12**	**2.15E+12**	**N/A**	**3.03E+12**
	Stdev	**3.53E+11**	**7.51E+09**	**N/A**	**1.59E+12**
	COV	**11.2%**	**0.3%**	**N/A**	**52.4%**
CARBz-CH	1	1.36E+14	2.04E+12	N/A	3.21E+12
	2	3.68E+14	2.37E+12	N/A	3.33E+12
	Avg	**2.52E+14**	**2.21E+12**	**N/A**	**3.27E+12**
	Stdev	**1.64E+14**	**2.35E+11**	**N/A**	**9.06E+10**
	COV	**65.1%**	**10.6%**	**N/A**	**2.8%**
16-Hour	1	4.34E+13	4.82E+13	1.82E+13	2.48E+13
	2	3.90E+13	6.54E+13	2.18E+13	4.55E+12
	3	4.14E+13	5.59E+13	9.74E+12	2.47E+13
	Avg	**4.13E+13**	**5.65E+13**	**2.45E+13**	**1.80E+13**
	Stdev	**2.18E+12**	**8.62E+12**	**3.93E+13**	**1.17E+13**
	COV	**5.3%**	**15.3%**	**160.6%**	**64.8%**



	Engine A	Engine B	Engine C	Engine D
FTP-w	4.81E+12	3.67E+12	2.26E+12	5.00E+12
FTP-wo	4.64E+13	2.66E+12	9.65E+11	6.92E+11
CARBx-ICT	3.15E+12	2.15E+12	N/A	3.03E+12
CARBz-CH	2.52E+14	2.21E+12	N/A	3.27E+12
16-Hour	4.13E+13	5.65E+13	2.45E+13	1.80E+13

FIGURE 41. AVERAGE EEPS-BASED BRAKE-SPECIFIC PM NUMBER EMISSIONS - EXPOSURE CHAMBER

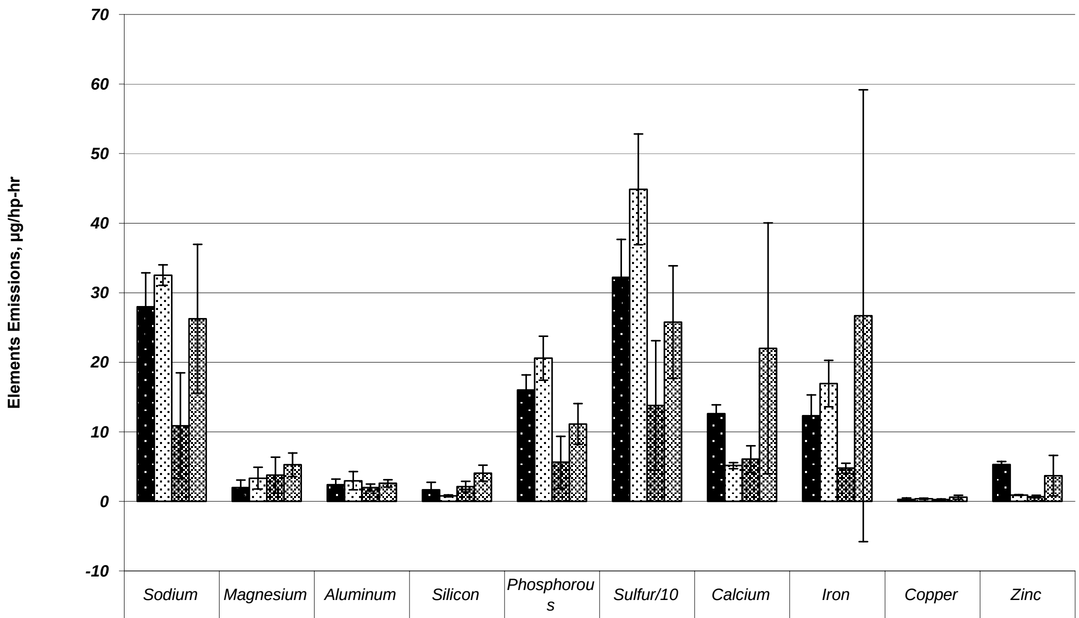
5.7.7 Metals and Other Elements

Table 30 shows a summary of total elements for all engines and cycles. It is important to note that the majority of the elements detected for the FTP, CARBx-ICT, and CARBz-CH were below the limit of detection for the X-ray fluorescence (XRF) analysis technique. Only the 16-Hour cycle presents data where the detected level was above the uncertainty level for certain elements (Figure 42). A more detailed list is included in Appendix D. Lube oil-derived elements such as phosphorus, sulfur, calcium, and zinc were observed, with the highest emissions from sulfur, which is also a fuel component. No vanadium was observed. Copper was only detected with the 16-Hour cycle.

TABLE 30. TOTAL ELEMENTAL BRAKE-SPECIFIC EMISSIONS

Test Cycle	Number of Repeats		Total Elements, µg/hp-hr			
			Engine A	Engine B	Engine C	Engine D
FTP-w[a]	3	Avg	805	1950	811	1449
		Stdev	11	49	68	98
		COV	1%	3%	8%	7%
FTP-wo[a]	3	Avg	745	2011	804	1343
		Stdev	71	217	14	297
		COV	9%	11%	2%	22%
CARBx-ICT[a]	2	Avg	3004	4293	3082	3592
		Stdev	814	67	972	526
		COV	27%	2%	32%	15%
CARBz-CH[a]	2	Avg	1625	587	551	393
		Stdev	570	38	281	33
		COV	35%	6%	51%	8%
16-Hour	3	Avg	413	541	185	376
		Stdev	62	85	109	77
		COV	15%	16%	59%	21%

[a] The great majority of the metallic elements detected were below the limit of the detection method.



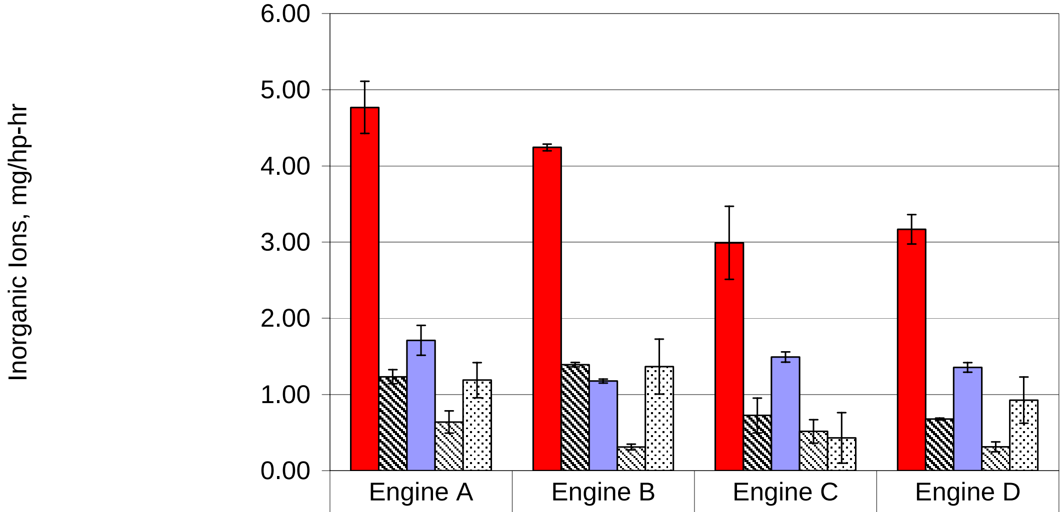
	Sodium	Magnesium	Aluminum	Silicon	Phosphorous	Sulfur/10	Calcium	Iron	Copper	Zinc
Engine A	27.99	1.99	2.41	1.67	16.02	32.22	12.61	12.32	0.28	5.29
Engine B	32.53	3.34	2.97	0.81	20.59	44.87	5.15	16.95	0.38	0.92
Engine C	10.87	3.78	1.98	2.12	5.62	13.78	6.09	4.79	0.26	0.70
Engine D	26.26	5.27	2.59	4.06	11.13	25.77	22.00	26.70	0.60	3.71

FIGURE 42. AVERAGE BRAKE-SPECIFIC ELEMENTS EMISSIONS FOR 16-HOUR CYCLE (ELEMENTS SHOWN ARE ABOVE LIMIT OF DETECTION)

5.8 Inorganic Ions Emissions

Inorganic ions were detected mainly in the 16-Hour cycle. Sulfate was the only ionic species that was detected in the particle phase. Inorganic ions collected in deionized water downstream of the sample filter were analyzed for chloride, nitrate, nitrite, sulfate, ammonium, and hydrogen ions, and pH. Only nitrate, nitrite, and sulfate, besides hydrogen ions, were detected in the water.

Figure 43 shows the brake-specific emissions of total inorganic ions (gas and particle phase), excluding hydrogen ions. Particle phase sulfate was two to three times higher than gas phase sulfate, except for Engine C, where the two had a similar level. Nitrate and nitrite were detected in the water downstream of the filter but neither of these species was observed on the filter. The average pH of the deionized water after collection during the 16-Hour cycle was about 4, as shown in Figure 44, suggesting that the solution was acidic. Figure 45 shows a comparison between measured filter-based sulfate as measured by IC and calculated sulfate from sulfur measured by the XRF method. Trends as well as the absolute emission levels were very similar between measured and calculated sulfate. Figure 46 shows a correlation between measured filter-based sulfate and sulfur. Good linear regression was observed with a coefficient of determination (R^2) of 0.93. The slope of the linear regression was 3, the same as the multiplier used to convert elemental sulfur into sulfate. This suggests that all the sulfur on the filter is in the form of SO_4^{2-}; providing evidence that there is little non-sulfate sulfur in the collected PM. In general, a large portion of PM emitted from 2007 engines is sulfate, which is derived from sulfur in the fuel and lube oil.



	Engine A	Engine B	Engine C	Engine D
Total Inorganic Ions	4.77	4.24	2.99	3.17
Gas Phase Nitrate	1.23	1.39	0.72	0.68
Gas Phase Nitrite	1.71	1.18	1.49	1.36
Gas Phase Sulfate	0.64	0.31	0.52	0.31
Particle Phase Sulfate	1.19	1.37	0.43	0.93

FIGURE 43. GAS AND PARTICLE PHASE INORGANIC IONS BRAKE-SPECIFIC EMISSIONS FOR THE 16-HOUR CYCLE

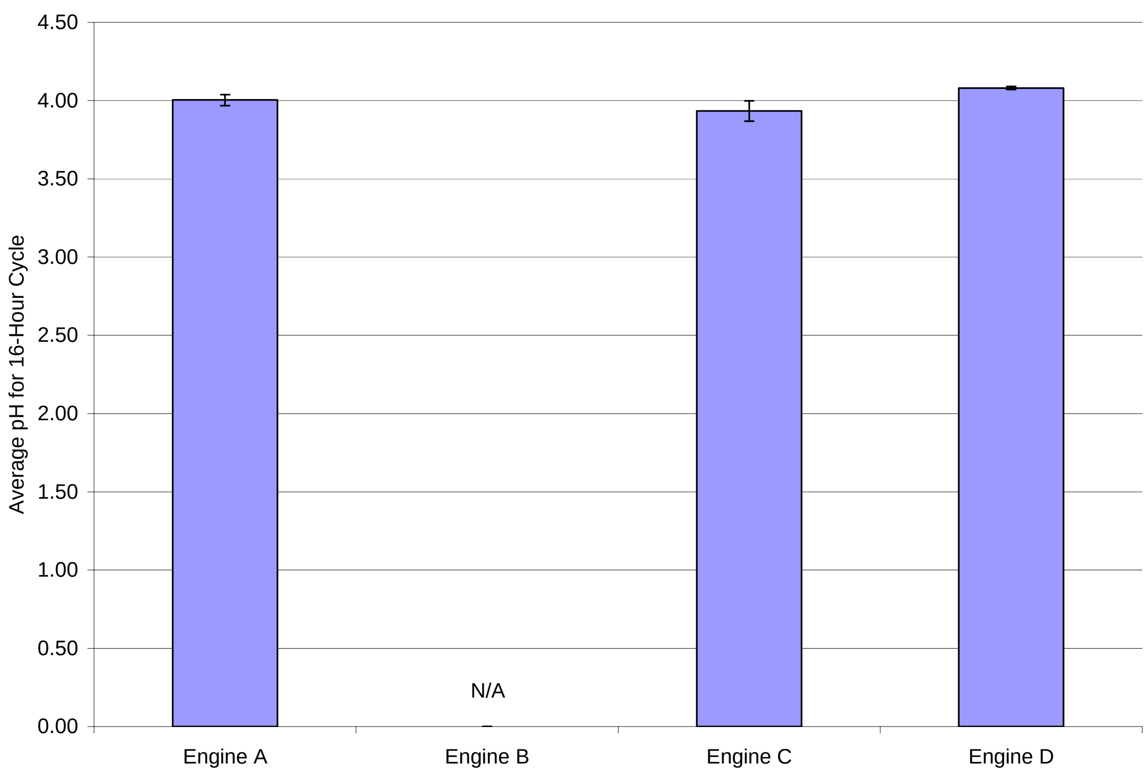
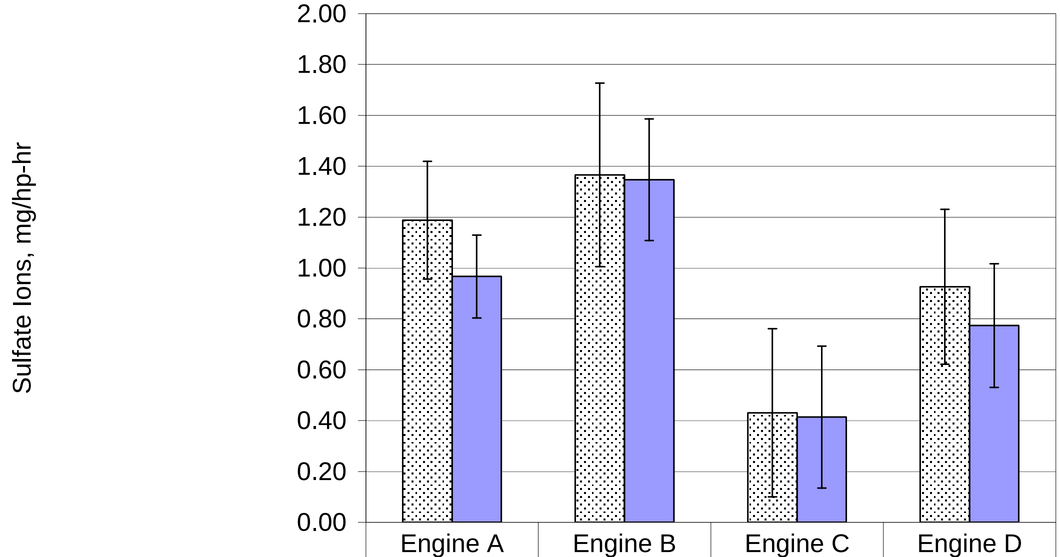


FIGURE 44. AVERAGE DEIONIZED WATER PH AFTER DILUTE EXHAUST COLLECTION DURING THE 16-HOUR CYCLE



	Engine A	Engine B	Engine C	Engine D
Measured Particle Phase Sulfate	1.19	1.37	0.43	0.93
Calculated Sulfate from Sulfur on Filter	0.97	1.35	0.41	0.77

FIGURE 45. MEASURED AND CALCULATED SULFATE PM FOR THE 16-HOUR CYCLE

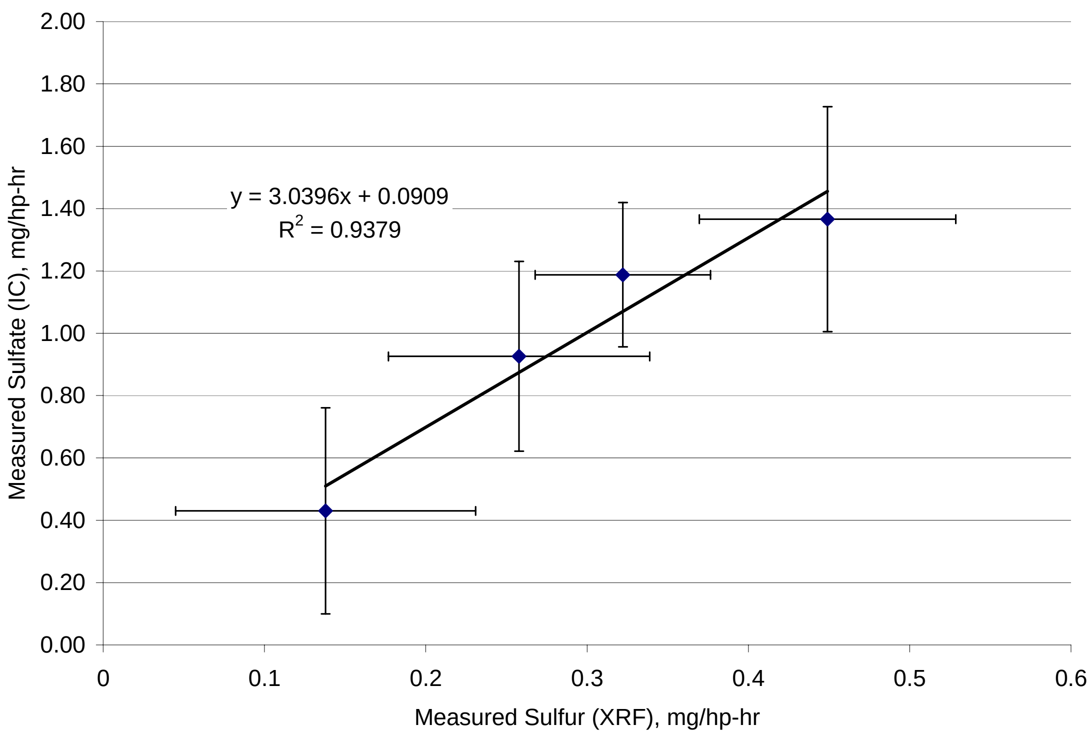


FIGURE 46. CORRELATION BETWEEN MEASURED FILTER-BASED SULFATE AND SULFUR

5.9 Carbonyl Emissions

Carbonyl compounds were detected mainly for the 16-Hour cycle and for the CARBx-ICT cycle. Figures 47 and 48 and Tables 31 and 32 show the carbonyl emissions species for all engines for the 16-Hour cycle and CARBx-ICT. Carbonyl emissions were dominated mainly by formaldehyde and acetaldehyde. Detailed carbonyl data are included in Appendix E. Figure 49 shows total carbonyl emissions for all engines and cycles. Brake-specific carbonyl emissions were the highest for the CARBx-ICT cycle. Generally, carbonyl compounds are either reported as negative values due to background subtraction or zero if the detection is below the laboratory blank.

5.10 Selected Hydrocarbon Speciation-C_1-C_{12}

Table 33 and Figure 50 summarize the BTEX (benzene, toluene, ethylbenzene, and mixed xylenes) emissions for the different engines and cycles. The lowest emission levels were from the 16-Hour cycle and ranged from 0.35 mg/hp-hr to 1.2 mg/hp-hr. CARBx-ICT again showed the highest emission levels. The highest emissions in the BTEX group were for m-& p-xylene. As for the other compounds, 1,3-butadiene was detected only for CARBx-ICT cycle. Ethylene was the highest hydrocarbon species emitted for the CARBx-ICT cycle, followed by propylene, on the order of 88 and 22 mg/hp-hr, respectively.

5.11 PAH Emissions

Table 34 and Figure 51 show a summary of total PAH, excluding any oxyPAH and nitroPAH. The sum of total brake-specific PAH emissions are the lowest for the CARBz-CH, which is the highest loaded cycle. The lightest loaded cycle, CARBx-ICT, showed the highest PAH emissions. PAH emissions were dominated by gas phase PAHs, and the largest contributors were naphthalene and F-trimethylnaphthalene (unspecified trimethyl naphthalene). Generally, higher molecular weight PAHs up to 4-ring showed higher emissions in the gas phase, compared to the particle phase. PAHs higher than 4-rings were mainly undetected.

Note that the tunnel blank (TB) PAH was based on a 20-minute run using the cycle work value of the FTP transient cycle. So, it is comparable with the FTP. The background (BG) run is based on a 16-Hour collection of CVS dilution air, from downstream of the HEPA filter. Note that the total PAH for the tunnel blank is similar to the levels with the FTP cycles. For the 16-Hour cycle, the BG emissions represents 50 to 100 percent of the 16-Hour cycle emissions.

5.12 OxyPAH Emissions

Table 35 and Figure 52 summarize the total oxyPAH emissions. Note that the sum of oxyPAHs is considerably lower than that of the PAHs.

The TB was comparable with FTP emission levels, but the 16-Hour cycle level was three to six times higher than that reported for BG dilution air, suggesting that oxyPAH formation is associated with engine operation or perhaps artifact formation during the long 16-Hour cycle. It is important to note that the oxyPAH emissions are reported in units of µg/hp-hr, while the total PAH emissions are reported in units of mg/hp-hr.

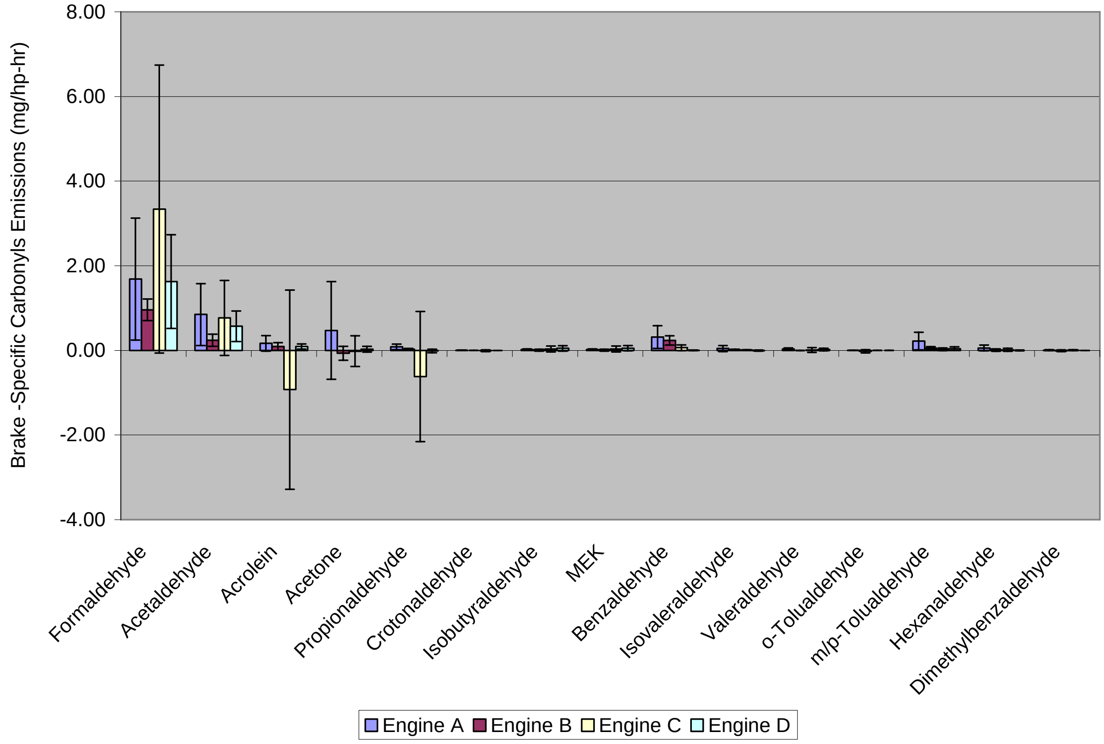


FIGURE 47. CARBONYL COMPOUND BRAKE-SPECIFIC EMISSIONS FOR 16-HOUR CYCLE

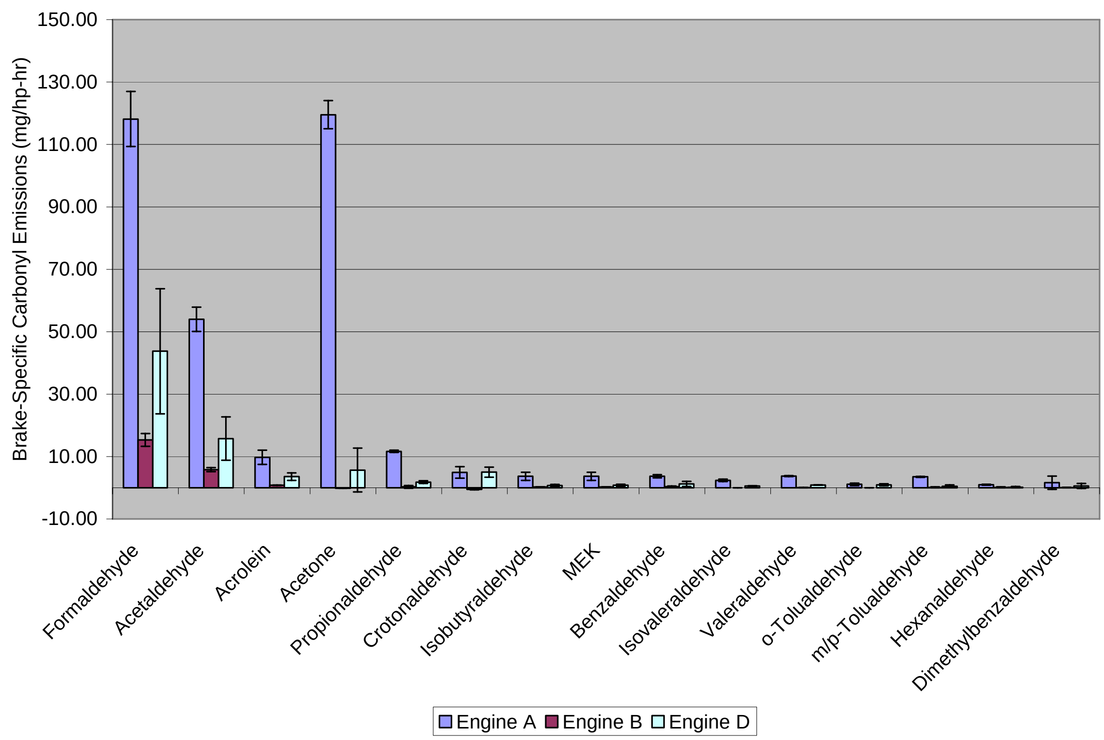


FIGURE 48. CARBONYL COMPOUND BRAKE-SPECIFIC EMISSIONS FOR CARBX-ICT

TABLE 31. CARBONYL COMPOUND BRAKE-SPECIFIC EMISSIONS FOR 16-HOUR CYCLE

	Brake Specific Carbonyls, mg/hp-hr, 16-Hour cycle							
	Engine A		Engine B		Engine C		Engine D	
	Avg.	Stdev	Avg.	Stdev	Avg.	Stdev	Avg.	Stdev
Formaldehyde	1.69	1.44	0.96	0.25	3.34	3.40	1.63	1.11
Acetaldehyde	0.85	0.73	0.24	0.14	0.77	0.89	0.57	0.36
Acrolein	0.17	0.18	0.09	0.09	-0.93	2.35	0.09	0.06
Acetone	0.47	1.15	-0.07	0.17	-0.02	0.36	0.03	0.07
Propionaldehyde	0.08	0.07	0.03	0.02	-0.62	1.54	-0.01	0.04
Crotonaldehyde	0.00	0.00	0.00	0.00	-0.01	0.02	0.00	0.00
Isobutyraldehyde	0.02	0.02	0.01	0.02	0.03	0.07	0.05	0.06
MEK	0.02	0.02	0.01	0.02	0.03	0.07	0.05	0.06
Benzaldehyde	0.32	0.27	0.23	0.11	0.06	0.07	0.00	0.01
Isovaleraldehyde	0.04	0.07	0.01	0.01	0.01	0.01	0.00	0.01
Valeraldehyde	0.03	0.03	0.00	0.00	0.01	0.06	0.02	0.03
o-Tolualdehyde	0.00	0.00	-0.02	0.04	0.00	0.00	0.00	0.00
m/p-Tolualdehyde	0.22	0.21	0.06	0.03	0.03	0.03	0.04	0.04
Hexanaldehyde	0.06	0.07	0.01	0.03	0.01	0.03	0.00	0.01
Dimethylbenzaldehyde	0.00	0.01	-0.01	0.02	0.00	0.01	0.00	0.00
Negative values are due to background subtraction Zero is reported if the measurement is below the analytical laboratory blank value								

TABLE 32. CARBONYL COMPOUND BRAKE-SPECIFIC EMISSIONS FOR CARBX-ICT

	Brake Specific Carbonyls, mg/hp-hr, 16-Hour cycle							
	Engine A		Engine B		Engine C		Engine D	
	Avg.	Stdev	Avg.	Stdev	Avg.	Stdev	Avg.	Stdev
Formaldehyde	118.16	8.78	15.33	2.04	N/A	N/A	43.74	20.03
Acetaldehyde	54.00	3.91	5.78	0.66	N/A	N/A	15.73	6.95
Acrolein	9.76	2.25	0.79	0.04	N/A	N/A	3.55	1.21
Acetone	119.55	4.52	-0.18	0.00	N/A	N/A	5.66	7.05
Propionaldehyde	11.67	0.33	0.29	0.45	N/A	N/A	1.82	0.44
Crotonaldehyde	4.92	1.85	-0.55	0.15	N/A	N/A	5.00	1.59
Isobutyraldehyde	3.67	1.28	0.25	0.03	N/A	N/A	0.75	0.31
MEK	3.67	1.28	0.25	0.03	N/A	N/A	0.76	0.32
Benzaldehyde	3.70	0.51	0.37	0.17	N/A	N/A	1.22	0.84
Isovaleraldehyde	2.38	0.39	0.00	0.00	N/A	N/A	0.56	0.09
Valeraldehyde	3.73	0.17	0.03	0.04	N/A	N/A	0.85	0.09
o-Tolualdehyde	1.07	0.41	0.00	0.00	N/A	N/A	0.94	0.36
m/p-Tolualdehyde	3.47	0.17	0.11	0.15	N/A	N/A	0.45	0.43
Hexanaldehyde	0.96	0.15	0.12	0.17	N/A	N/A	0.18	0.21
Dimethylbenzaldehyde	1.62	2.15	0.06	0.09	N/A	N/A	0.55	0.78
Negative values are due to background subtraction Zero is reported if the measurement is below the analytical laboratory blank value								

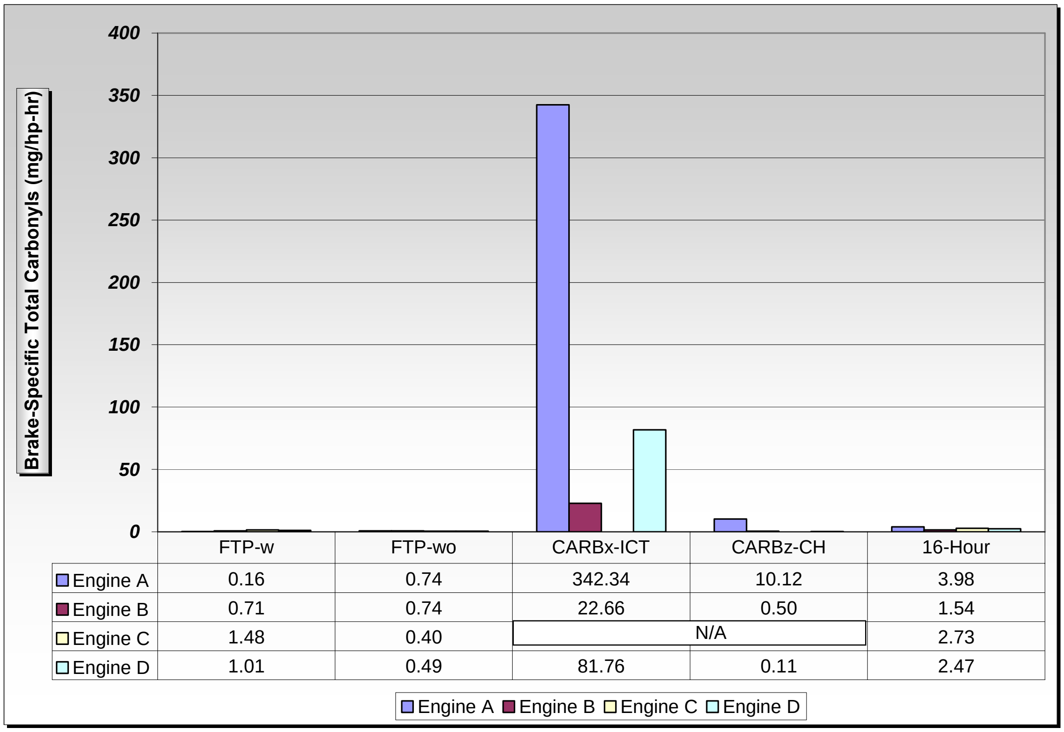


FIGURE 49. TOTAL CARBONYL COMPOUND BRAKE-SPECIFIC EMISSIONS FOR ALL ENGINES AND CYCLES

TABLE 33. TOTAL BTEX COMPOUND BRAKE-SPECIFIC EMISSIONS

Test Cycle	Number of Repeats		BTEX, mg/hp-hr			
			Engine A	**Engine B**	**Engine C**	**Engine D**
FTP-w	3	**Avg**	0.67	0.88	3.06	0.49
		Stdev	0.36	0.23	1.27	0.40
		COV	53.0%	26.1%	41.4%	81.2%
FTP-wo	3	**Avg**	0.61	1.20	0.01	0.25
		Stdev	0.26	1.38	0.02	0.05
		COV	42.5%	115.4%	173.2%	20.2%
CARBx-ICT	2	**Avg**	4.08	5.25	N/A	11.15
		Stdev	0.11	1.75	N/A	3.50
		COV	2.7%	33.3%	N/A	31.4%
CARBz-CH	2	**Avg**	0.63	1.32	N/A	0.95
		Stdev	0.28	0.05	N/A	0.15
		COV	44.8%	4.1%	N/A	15.6%
16-Hour	3	**Avg**	0.35	1.20	0.81	0.69
		Stdev	0.11	0.22	0.14	0.17
		COV	32.8%	18.5%	16.8%	24.3%

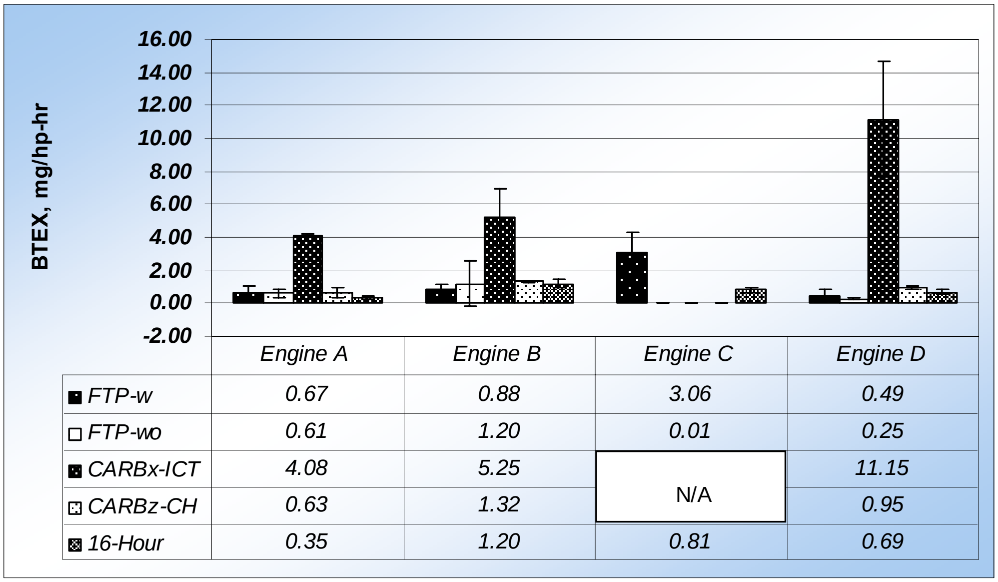


FIGURE 50. AVERAGE TOTAL BTEX COMPOUND BRAKE-SPECIFIC EMISSIONS FOR DIFFERENT ENGINES AND CYCLES

TABLE 34. SUMMARY OF PAH COMPOUND BRAKE-SPECIFIC EMISSIONS

Test Cycle	Number of Repeats		Total PAH, mg/hp-hr			
			Engine A	**Engine B**	**Engine C**	**Engine D**
FTP-w	3	**Avg**	1.01	1.00	3.17	1.23
		Stdev	0.03	0.24	0.79	0.16
		COV	3.2%	24.3%	24.9%	12.8%
FTP-wo	3	**Avg**	0.97	1.02	1.19	1.35
		Stdev	0.55	0.10	0.13	0.26
		COV	56.2%	9.6%	11.2%	19.5%
CARBx-ICT	2	**Avg**	13.48	4.12	N/A	20.86
		Stdev	5.64	0.14	N/A	2.48
		COV	41.8%	3.3%	N/A	11.9%
CARBz-CH	2	**Avg**	0.79	0.68	N/A	0.92
		Stdev	0.02	0.05	N/A	0.18
		COV	3.0%	8.1%	N/A	19.4%
16-Hour	3	**Avg**	0.56	0.75	0.86	0.81
		Stdev	0.08	0.06	0.43	0.25
		COV	13.7%	8.0%	49.8%	30.8%
TB	3	**Avg**	0.92	0.51	1.00	1.23
		Stdev	0.25	0.10	0.34	0.84
		COV	27.6%	20.3%	33.8%	68.6%
BG	1	**Value**	0.44	0.43	0.45	0.40
Because the analytical lab reported data below the limit of detection, the actual values reported were included in the summation, regardless of whether or not the value is above or below the limit of detection. Except for the 16-Hour cycle, many compounds were below the limit of detection and can contribute to the total sum.						

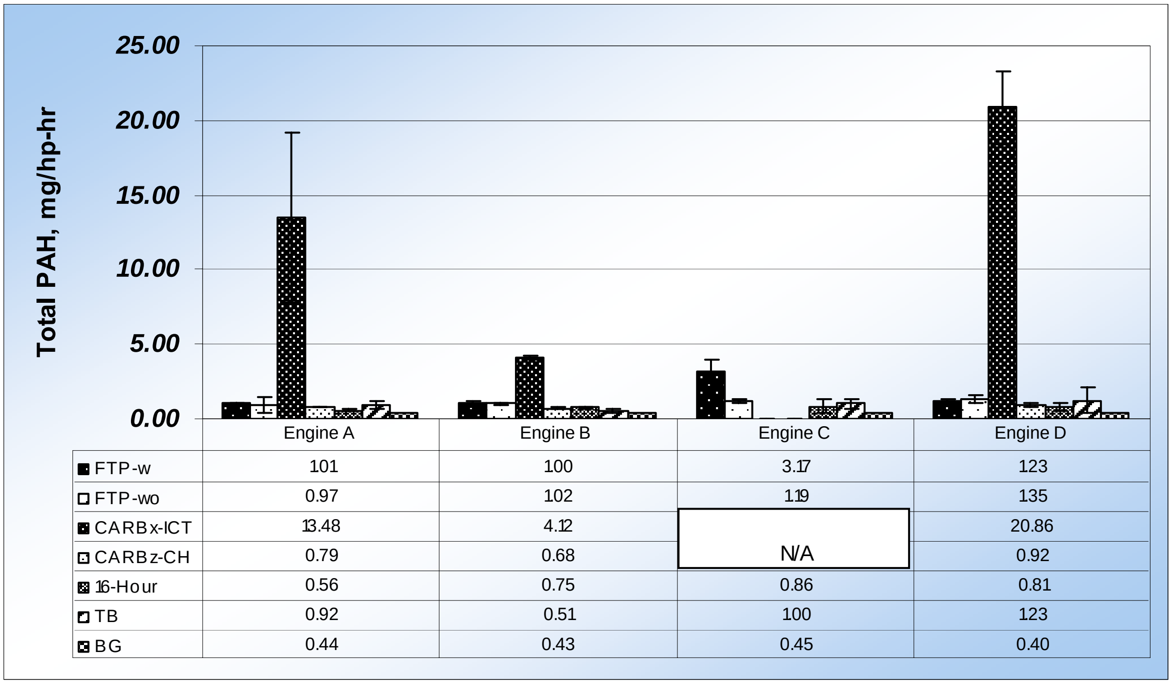


FIGURE 51. PAH COMPOUND BRAKE-SPECIFIC EMISSIONS

TABLE 35. SUMMARY OF OXYPAH COMPOUND BRAKE-SPECIFIC EMISSIONS

Test Cycle	Number of Repeats		OxyPAH, µg/hp-hr			
			Engine A	Engine B	Engine C	Engine D
FTP-w	3	**Avg**	5.66	4.68	5.09	2.26
		Stdev	0.39	4.00	4.87	1.47
		COV	6.8%	85.5%	95.8%	65.1%
FTP-wo	3	**Avg**	11.29	5.37	2.86	2.71
		Stdev	8.88	1.26	1.69	0.54
		COV	78.7%	23.5%	59.1%	19.8%
CARBx-ICT	2	**Avg**	29.80	16.63	N/A	47.20
		Stdev	16.67	0.70	N/A	11.02
		COV	55.9%	4.2%	N/A	23.4%
CARBz-CH	2	**Avg**	2.62	2.51	N/A	0.78
		Stdev	1.18	0.19	N/A	0.30
		COV	45.1%	7.7%	N/A	39.0%
16-Hour	3	**Avg**	6.25	5.96	3.76	3.29
		Stdev	1.08	0.68	1.84	0.76
		COV	17.2%	11.5%	49.0%	23.0%
TB	3	**Avg**	3.61	1.55	3.45	3.38
		Stdev	2.23	0.64	4.11	3.26
		COV	61.8%	41.4%	119.1%	96.6%
BG	1	**Value**	1.07	1.05	1.10	0.98
Because the analytical lab reported data below the limit of detection, the actual values reported were included in the summation, regardless of whether or not the value is above or below the limit of detection. Except for the 16-Hour cycle, many compounds were below the limit of detection and can contribute to the total sum.						

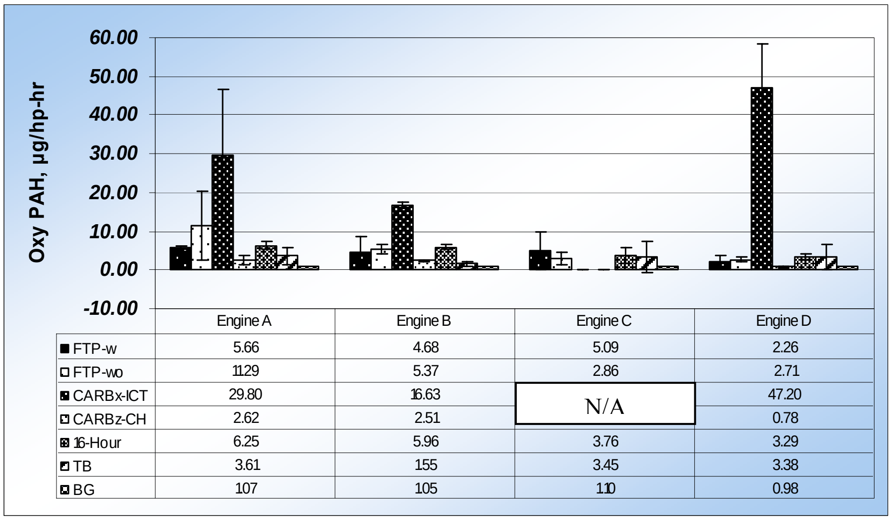


FIGURE 52. OXYPAH COMPOUND BRAKE-SPECIFIC EMISSIONS

5.13 NitroPAH Emissions

Table 36 and Figure 53 show total brake-specific nitroPAH emissions. NitroPAH emissions for the 16-Hour cycle were a factor of 2 to 3 times higher than background levels. Also, FTP cycle emissions were more than a factor of 20 higher than the tunnel blank, but due to measurement uncertainty at such as low emission level, no conclusions can be drawn.

5.14 Alcohol and Organic Acid Compound Emissions

Table 37 and Figure 54 show a summary of alcohol and organic acid compound brake-specific emissions. For the 16-Hour cycle, alcohol and organic compound emissions were a factor of 43 to 100 higher than background. For the FTP, the emissions were only a factor of 1.1 to 4.3 higher than a tunnel blank. This suggests that during a short sampling time of 20 minutes, the outgassing of material can have a major contribution to the reported emissions value for cycles like the FTP, CARBx-ICT, and CARBz-CH.

5.15 Hopanes/Steranes Emissions

Table 38 and Figure 55, and Table 39 and Figure 56 summarize the results for hopanes and steranes. Hopanes and steranes were found in the lube oil. Since the FTP ran with and without blow-by, one would expect that the runs without blow-by would have had lower hopanes and steranes emissions. That was the case for Engines A, B, and D. Only Engine C had lower hopanes and steranes emissions when the engine ran with blow-by added to the exhaust. There were very little hopanes and steranes measured in the background air.

TABLE 36. SUMMARY OF NITROPAH COMPOUND BRAKE-SPECIFIC EMISSIONS

Test Cycle	Number of Repeats		NitroPAH, µg/hp-hr			
			Engine A	Engine B	Engine C	Engine D
FTP-w	3	**Avg**	2.36	1.51	4.17	0.57
		Stdev	0.08	0.44	0.57	0.34
		COV	3.5%	29.2%	13.6%	59.0%
FTP-wo	3	**Avg**	1.65	1.89	1.05	0.06
		Stdev	1.22	0.96	0.69	0.06
		COV	73.7%	50.6%	65.9%	93.2%
CARBx-ICT	2	**Avg**	7.71	7.83	N/A	10.86
		Stdev	3.95	1.20	N/A	6.06
		COV	51.3%	0.15	N/A	55.8%
CARBz-CH	2	**Avg**	1.50	1.91	N/A	0.51
		Stdev	0.44	0.17	N/A	0.05
		COV	29.6%	0.09	N/A	10.3%
16-Hour	3	**Avg**	0.40	0.77	0.86	0.58
		Stdev	0.20	0.38	0.23	0.04
		COV	50.5%	49.3%	26.6%	7.5%
TB	3	**Avg**	0.10	0.68	0.26	0.09
		Stdev	0.12	0.55	0.30	0.15
		COV	117.0%	81.1%	115.5%	164.6%
BG	1	**Value**	0.22	0.21	0.23	0.20
Because the analytical lab reported data below the limit of detection, the actual values reported were included in the summation, regardless of whether or not the value is above or below the limit of detection. Except for the 16-Hour cycle, many compounds were below the limit of detection and can contribute to the total sum.						

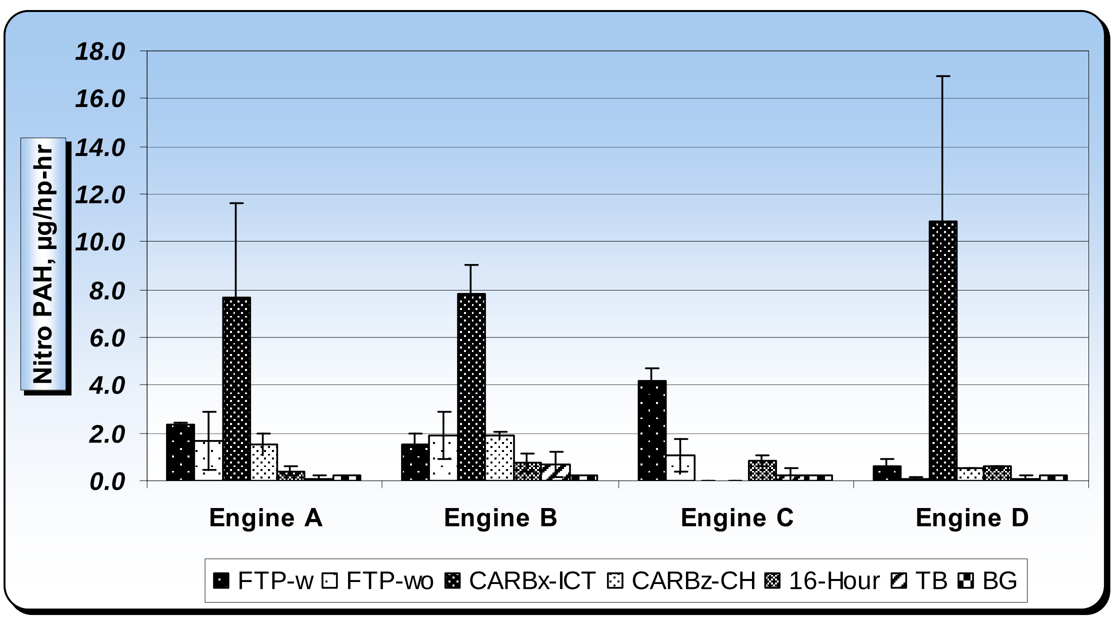


FIGURE 53. NITROPAH COMPOUND BRAKE-SPECIFIC EMISSIONS

TABLE 37. SUMMARY OF ALCOHOL AND ORGANIC ACID COMPOUND BRAKE-SPECIFIC EMISSIONS

Test Cycle	Number of Repeats		Alcohol and Organic Acid Compounds, mg/hp-hr			
			Engine A	Engine B	Engine C	Engine D
FTP-w	3	**Avg**	12.60	8.36	16.14	11.50
		Stdev	4.00	0.91	8.66	1.21
		COV	32%	11%	54%	10%
FTP-wo	3	**Avg**	11.88	12.16	9.75	7.92
		Stdev	2.50	3.16	5.57	6.04
		COV	21%	26%	57%	76%
CARBx-ICT	2	**Avg**	31.07	18.36	N/A	29.12
		Stdev	12.29	6.00	N/A	13.23
		COV	40%	33%	N/A	45%
CARBz-CH	2	**Avg**	7.17	2.84	N/A	2.52
		Stdev	1.55	0.19	N/A	0.22
		COV	22%	7%	N/A	9%
16-Hour	3	**Avg**	1.43	0.87	1.27	0.99
		Stdev	0.28	0.13	0.02	0.14
		COV	19%	15%	2%	15%
TB	3	**Avg**	4.55	7.54	3.68	7.79
		Stdev	2.20	2.83	4.71	5.57
		COV	48%	38%	128%	72%
BG	3	**Value**	0.084	0.082	0.086	0.077

Because the analytical lab reported data below the limit of detection, the actual values reported were included in the summation, regardless of whether or not the value is above or below the limit of detection. Except for the 16-Hour cycle, many compounds were below the limit of detection and can contribute to the total sum.

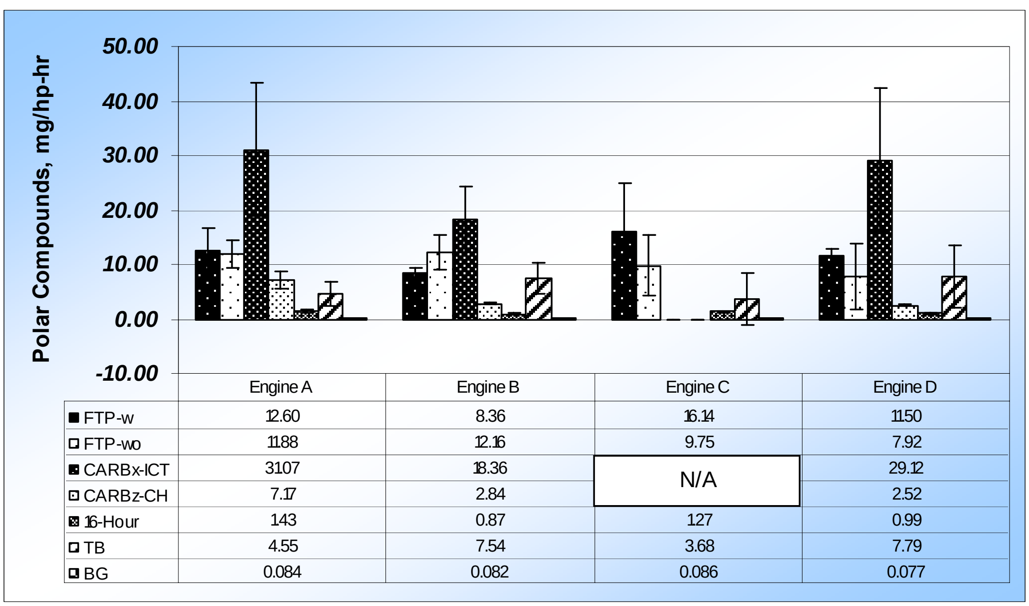


FIGURE 54. ALCOHOL AND ORGANIC ACID COMPOUNDS BRAKE-SPECIFIC EMISSIONS

TABLE 38. HOPANES BRAKE-SPECIFIC EMISSIONS

Test Cycle	Number of Repeats		Total Hopanes, µg/hp-hr			
			Engine A	**Engine B**	**Engine C**	**Engine D**
FTP-w	3	**Avg**	1.93	0.38	0.11	0.78
		Stdev	0.25	0.10	0.02	0.07
		COV	13.0%	26.0%	18.7%	8.7%
FTP-wo	3	**Avg**	0.65	0.22	0.48	0.58
		Stdev	0.23	0.05	0.10	0.04
		COV	35.7%	24.0%	21.6%	6.2%
CARBx-ICT	2	**Avg**	4.18	0.73	N/A	2.34
		Stdev	2.05	0.02	N/A	0.29
		COV	49.0%	2.7%	N/A	12.5%
CARBz-CH	2	**Avg**	0.79	0.14	N/A	0.31
		Stdev	0.14	0.00	N/A	0.02
		COV	17.8%	0.4%	N/A	7.1%
16-Hour	3	**Avg**	2.15	0.10	0.10	0.22
		Stdev	1.39	0.01	0.01	0.07
		COV	64.9%	8.8%	12.0%	29.9%
TB	3	**Avg**	0.97	0.07	0.07	0.49
		Stdev	0.58	0.02	0.02	0.22
		COV	60.0%	28.3%	28.3%	45.3%
BG	1	**Value**	0.02	0.02	0.02	0.02
Because the analytical lab reported data below the limit of detection, the actual values reported were included in the summation, regardless of whether or not the value is above or below the limit of detection. Except for the 16-Hour cycle, many compounds were below the limit of detection and can contribute to the total sum.						

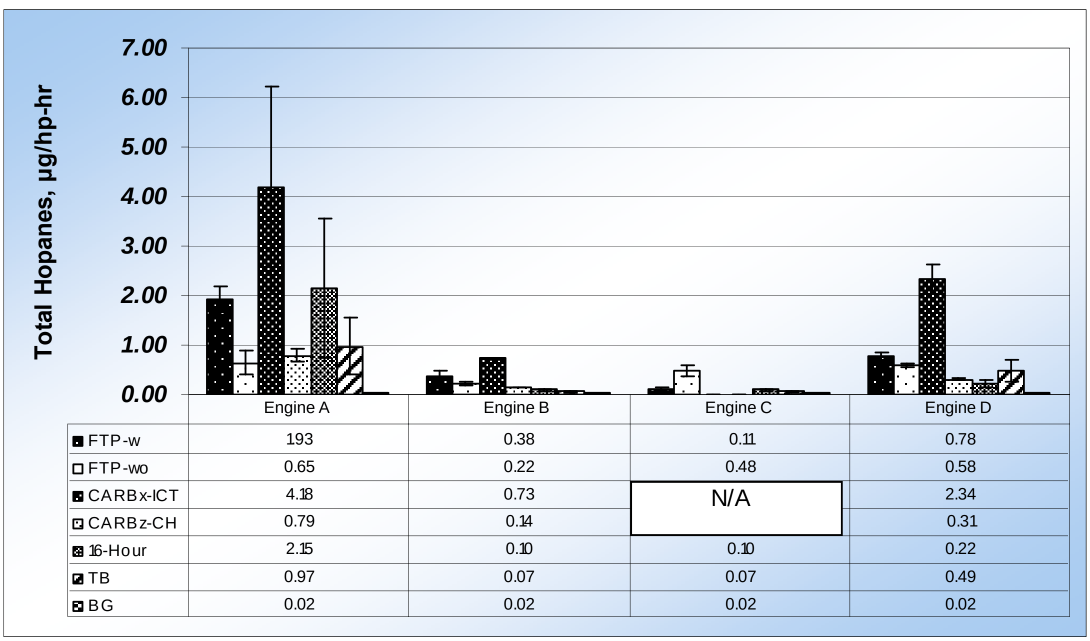


FIGURE 55. AVERAGE HOPANES BRAKE-SPECIFIC EMISSIONS

TABLE 39. STERANES BRAKE-SPECIFIC EMISSIONS

Test Cycle	Number of Repeats		Total Steranes, µg/hp-hr			
			Engine A	Engine B	Engine C	Engine D
FTP-w	3	**Avg**	0.54	0.14	0.08	0.17
		Stdev	0.09	0.03	0.01	0.04
		COV	17.1%	23.0%	8.2%	22.3%
FTP-wo	3	**Avg**	0.17	0.12	0.20	0.09
		Stdev	0.22	0.03	0.12	0.01
		COV	131.2%	21.9%	58.5%	11.6%
CARBx-ICT	2	**Avg**	0.93	0.25	N/A	0.60
		Stdev	1.32	0.00	N/A	0.08
		COV	141.4%	0.4%	N/A	13.9%
CARBz-CH	2	**Avg**	0.30	0.06	N/A	0.12
		Stdev	0.03	0.00	N/A	0.00
		COV	11.0%	3.3%	N/A	1.1%
16-Hour	3	**Avg**	1.56	0.03	0.05	0.11
		Stdev	1.07	0.00	0.01	0.04
		COV	68.7%	12.9%	13.4%	37.6%
TB	3	**Avg**	0.22	0.03	0.03	0.06
		Stdev	0.13	0.03	0.03	0.01
		COV	59.8%	83.6%	83.6%	24.3%
BG	1	**Value**	0.02	0.02	0.02	0.02

Because the analytical lab reported data below the limit of detection, the actual values reported were included in the summation, regardless of whether or not the value is above or below the limit of detection. Except for the 16-Hour cycle, many compounds were below the limit of detection and can contribute to the total sum.

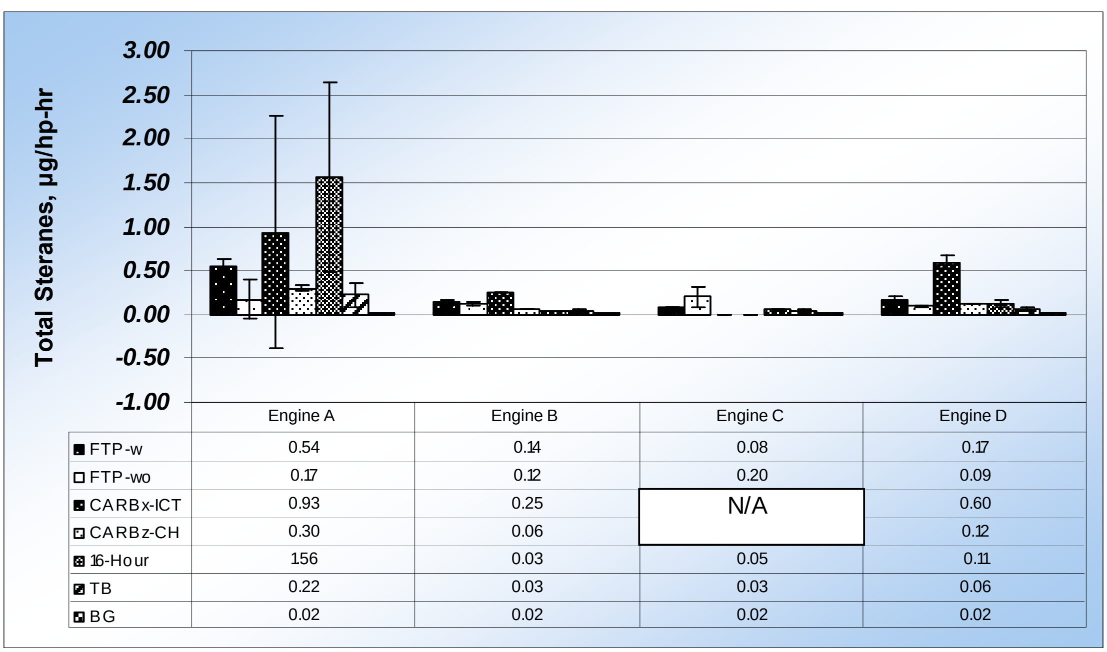


FIGURE 56. AVERAGE STERANES BRAKE-SPECIFIC EMISSIONS

5.16 Dioxins/Furans Emissions

Tables 40, 41, and 42 show the toxic equivalent (TEQ) mass of the 17 dioxin and furan compounds, for Engines A, C, and D, respectively. The toxic equivalency factor (TEF) is shown for each compound, along with the TEQ values in picograms. Essentially, the mass shown in the tables is the TEQ mass collected by an 8x10 filter and a PUF XAD during the16-Hour transient cycle, and during a 16 hour background air collection.

Table 43 shows TEQ brake-specific emissions for actual engine operation, background, and for net emissions determined by subtracting the background. The net brake-specific emissions level was below 0.5 picogram/hp-hr. The total TEQ of dioxins/furans emitted during the 16 hour cycle ranged from about 45 to 600 picograms. The average concentration in the exposure chamber ranged from about 0.006 to 0.08 picograms per cubic meter.

In a 1996 and 1998 on-highway diesel truck tunnel study [2], the TEQ was estimated to be about 946 picograms per liter of diesel fuel. The calculated TEQ emissions in this work ranges from 0.13 to 1.4 picogram per liter of diesel fuel, which represents a greater than 99.9 percent reduction.

Table 44 shows the sum of tetra-, penta-, hexa-, and hepta- dioxins/furans. Total dioxin/furan emissions are a factor of 100 higher than the toxic-equivalent dioxins/furans.

Table 45 shows the presence of total chlorine in fresh and used lube oil for Engine C and D. The concentration by mass is on the order of 120 ppm. Table 46 shows the concentration of chlorine and chloride, and total chlorine (sum of chlorine and chloride) in the background air and also in engine intake air. Engine intake air is typically humidified with a water spray to meet target levels of relative humidity and temperature required by CFR Part 1065. The elevated chlorine level in the intake air may be due to the chlorine contained in the water spray. Both intake air chlorine and chlorine in the lube oil may contribute to dioxin and furan formation.

5.17 Cyanide, Sulfide, and Hexavalent Chromium Emissions

The emissions for cyanide, sulfide, and hexavalent chromium were all below the lowest detection limit, which was about 0.6, 11.5, and 0.1 μg/hp-hr, respectively, for the 16-Hour cycle.

5.18 Nitrosamines Emissions

Table 47 and Figure 57 show a summary of total nitrosamines. For the 16-Hour cycle, N-nitrosodi-N-methylamine (NDMA) dominated the emissions. For the rest of the cycles and engines, the emissions mainly contained N-nitrosodi-N-ethylamine (NDEA) besides NDMA. Detailed data are included in Appendix F.

TABLE 40. TEQ MASS OF DIOXINS/FURANS COLLECTED DURING 16-HOUR CYCLE FOR ENGINE A AND BACKGROUND SAMPLE

Engine A TEQ Dioxins/Furans, ng/sample					
TEQ Summary		16-Hour Cycle XAD	16-Hour Cycle 8 x 10 Filter	16-Hour Background XAD	16-Hour Background 8 x 10 Filter
ANALYTE	TEF				
2,3,7,8-TCDD	1	0	0	0	0
1,2,3,7,8-PeCDD	0.5	0	0	0.0314	0
1,2,3,4,7,8-HxCDD	0.1	0.052	0	0	0
1,2,3,6,7,8-HxCDD	0.1	0.0908	0	0	0
1,2,3,7,8,9-HxCDD	0.1	0.145	0	0	0
1,2,3,4,6,7,8-HpCDD	0.01	0.0462	0	0.0408	0.0345
OCDD	0.001	0.02548	0.0177	0.00586	0
2,3,7,8-TCDF	0.1	1.56	0.172	0.808	0
1,2,3,7,8-PeCDF	0.05	0.3925	0.04625	0.1155	0
2,3,4,7,8-PeCDF	0.5	0	0	0.715	1.04
1,2,3,4,7,8-HxCDF	0.1	0.248	0.392	0.28	0.351
1,2,3,6,7,8-HxCDF	0.1	0.528	0.262	0.1315	0.21
1,2,3,7,8,9-HxCDF	0.1	0	0	0	0
2,3,4,6,7,8-HxCDF	0.1	0	0.286	0.0638	0
1,2,3,4,6,7,8-HpCDF	0.01	0	0	0	0
1,2,3,4,7,8,9-HpCDF	0.01	0	0	0	0
OCDF	0.001	0.00795	0.008	0.00587	0.00257
Total TEQ, ng/sample		**3.10**	**1.18**	**2.20**	**1.64**
TEQ: toxic equivalent mass that is obtained by multiplying the measured mass per sample of a particular compound by the toxic equivalent factor (TEF)					

TABLE 41. TEQ MASS OF DIOXINS/FURANS COLLECTED DURING 16-HOUR CYCLE FOR ENGINE C AND BACKGROUND SAMPLE

Engine C TEQ Dioxins/Furans, ng/sample					
TEQ Summary		16-Hour Cycle XAD	16-Hour Cycle 8 x 10 Filter	16-Hour Background XAD	16-Hour Background 8 x 10 Filter
ANALYTE	TEF				
2,3,7,8-TCDD	1	0	0	0	0
1,2,3,7,8-PeCDD	0.5	0	0	0	0
1,2,3,4,7,8-HxCDD	0.1	0.146	0.21	0	0
1,2,3,6,7,8-HxCDD	0.1	0	0.193	0	0
1,2,3,7,8,9-HxCDD	0.1	0.243	0.484	0.164	0
1,2,3,4,6,7,8-HpCDD	0.01	0.0761	0.0498	0.0505	0.0483
OCDD	0.001	0.0544	0.0126	0.03328	0.0135
2,3,7,8-TCDF	0.1	1.522	0.409	1.041	0
1,2,3,7,8-PeCDF	0.05	0.211	0.149	0.0705	0
2,3,4,7,8-PeCDF	0.5	4.215	2.48	3.005	1.39
1,2,3,4,7,8-HxCDF	0.1	0.825	0.719	0	0
1,2,3,6,7,8-HxCDF	0.1	0.296	0	0.1963	0
1,2,3,7,8,9-HxCDF	0.1	0.218	0	0	0
2,3,4,6,7,8-HxCDF	0.1	0.21	0	0.107	0
1,2,3,4,6,7,8-HpCDF	0.01	0	0	0	0
1,2,3,4,7,8,9-HpCDF	0.01	0.063	0	0	0
OCDF	0.001	0.00393	0.00715	0.00212	0.00481
Total TEQ, ng/sample		**8.08**	**4.71**	**4.67**	**1.46**
TEQ: toxic equivalent mass that is obtained by multiplying the measured mass per sample of a particular compound by the toxic equivalent factor (TEF)					

TABLE 42. TEQ MASS OF DIOXINS/FURANS COLLECTED DURING 16-HOUR CYCLE FOR ENGINE D AND BACKGROUND SAMPLE

Engine D TEQ Dioxins/Furans, ng/sample						
TEQ Summary						
ANALYTE	TEF	16-Hour Cycle XAD	16-Hour Cycle 8 x 10 Filter		16-Hour Background XAD	16-Hour Background 8 x 10 Filter
2,3,7,8-TCDD	1	0	0		0	0
1,2,3,7,8-PeCDD	0.5	0	0		0	0
1,2,3,4,7,8-HxCDD	0.1	0.037	0		0	0
1,2,3,6,7,8-HxCDD	0.1	0.088	0		0	0
1,2,3,7,8,9-HxCDD	0.1	0	0.679		0	0
1,2,3,4,6,7,8-HpCDD	0.01	0.0263	0.0881		0.0369	0.0689
OCDD	0.001	0.0468	0.0218		0.04597	0.0172
2,3,7,8-TCDF	0.1	1.282	0.24		0.72	0
1,2,3,7,8-PeCDF	0.05	0.105	0.161		0.182	0
2,3,4,7,8-PeCDF	0.5	5.69	3.005		0	1.775
1,2,3,4,7,8-HxCDF	0.1	0.3	0		0	0.443
1,2,3,6,7,8-HxCDF	0.1	0	0.616		0.244	0.304
1,2,3,7,8,9-HxCDF	0.1	0	0		0	0
2,3,4,6,7,8-HxCDF	0.1	0.0912	0		0.149	0.287
1,2,3,4,6,7,8-HpCDF	0.01	0	0		0	0
1,2,3,4,7,8,9-HpCDF	0.01	0	0		0	0
OCDF	0.001	0.00695	0.00426		0.00832	0.00624
Total TEQ, ng/sample		**7.67**	**4.82**		**1.39**	**2.90**
TEQ: toxic equivalent mass that is obtained by multiplying the measured mass per sample of a particular compound by the toxic equivalent factor (TEF)						

TABLE 43. TEQ DIOXINS/FURANS BRAKE-SPECIFIC EMISSIONS AND CONCENTRATION

	Engine picogram/hp-hr	Background picogram/hp-hr	Net[a] picogram/hp-hr	Net[a] per Cycle picograms	Net[a] Exposure Chamber picogram/m³
Engine A	0.36	0.34	0.04	70.72	0.0008
Engine C	1.51	0.38	1.15	1455.79	0.0161
Engine D	0.92	0.25	0.68	1282.34	0.0140
[a] The net value background corrected using Xnet = Xr-(1-1/DR)*Xbg, where Xr is the reported emissions without background correction, Xbg is the reported emissions for background, and DR is the average dilution ratio in the CVS during the 16-Hour cycle.					

TABLE 44. TOTAL DIOXINS/FURANS BRAKE-SPECIFIC EMISSIONS AND CONCENTRATION

	Engine picogram/hp-hr	Background picogram/hp-hr	Net[a] picogram/hp-hr	Net[a] per Cycle picograms	Net[a] Exposure Chamber picogram/m^3
Engine A	35.43	11.59	24.42	42732.34	0.4869
Engine C	30.55	15.58	15.71	19845.59	0.2199
Engine D	32.01	9.82	22.61	42609.63	0.4654

[a] The net value background corrected using Xnet = Xr-(1-1/DR)*Xbg, where Xr is the reported emissions without background correction, Xbg is the reported emissions for background, and DR is the average dilution ratio in the CVS during the 16-Hour cycle.

TABLE 45. TOTAL CHLORINE IN ENGINE LUBRICANT

SwRI Code	Source	Result, mg/kg
EM-3275-EO	New Oil	120
EM-3277-EO	Engine C	124
EM-3282-EO	Engine D	130
Duplicate result	Engine D	133

TABLE 46. TOTAL CHLORINE IN AIR

	Chlorine, Cl_2, μg/m^3	Chloride, Cl^-, μg/m^3	Total Chlorine, μg/m^3
C16H-62 Engine C Intake Air	85	98	183
C16H-62-BG	61	75	136
D16H60 Engine D Intake Air	82	94	176
D16H60-BG	124	<69	~158

TABLE 47. NITROSAMINES BRAKE-SPECIFIC EMISSIONS

Test Cycle	Number of Repeats		Nitrosamines, µg/hp-hr			
			Engine A	Engine B	Engine C	Engine D
FTP-w	3	Avg	168.0	137.6	73.5	429.6
		Stdev	199.6	87.5	11.8	203.3
		COV	119%	64%	16%	47%
FTP-wo	3	Avg	N/A	105.0	118.2	179.0
		Stdev	N/A	64.8	78.7	310.0
		COV	N/A	61.7%	66.6%	173.2%
CARBx-ICT	2	Avg	442.8	60.3	N/A	839.5
		Stdev	626.2	85.2	N/A	1187.2
		COV	141%	141%	N/A	141%
CARBz-CH	2	Avg	114.6	86.0	N/A	29.6
		Stdev	89.3	36.8	N/A	0.2
		COV	78%	43%	N/A	1%
16-Hour	3	Avg	46.5	107.7	100.6	26.6
		Stdev	14.2	140.9	74.6	8.5
		COV	30%	131%	74%	32%

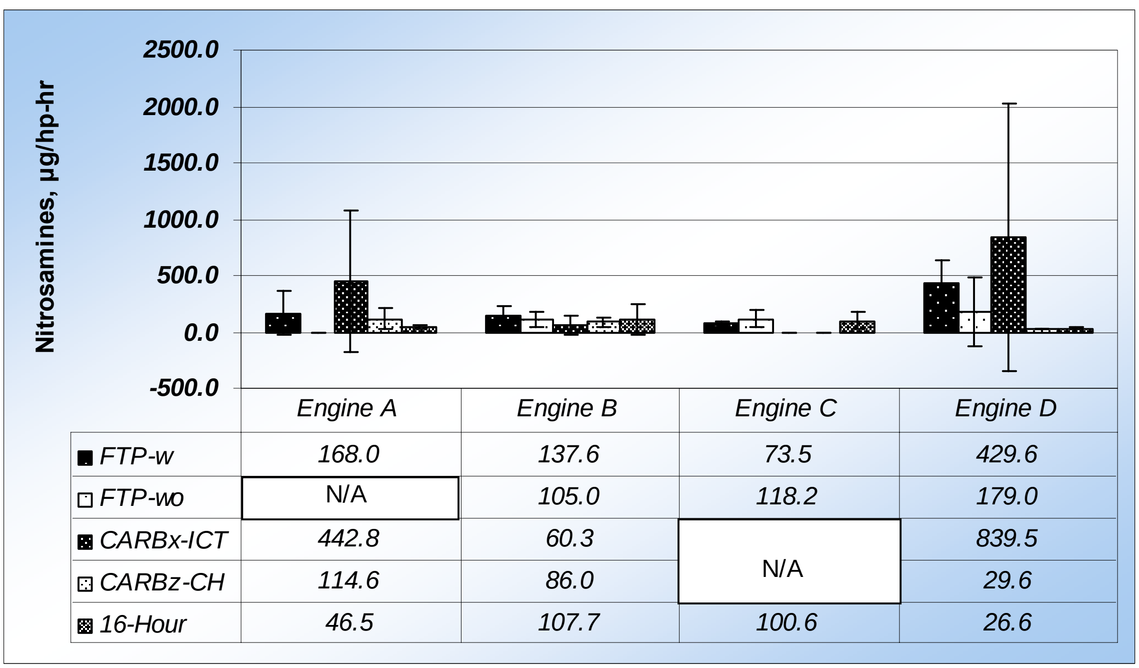


FIGURE 57. AVERAGE TOTAL NITROSAMINES EMISSIONS

5.19 Selected VOC Emissions

Table 48 and Figure 58 show the brake-specific emissions of selected VOCs. These included carbonyl sulfide (COS), nitromethane, nitroethane, 2-nitropropane, and 1-nitropropane. Generally, COS and nitromethane (CH_3NO_2) dominated the selected VOC compound emissions.

TABLE 48. SELECTED VOC COMPOUND BRAKE-SPECIFIC EMISSIONS

Test Cycle	Number of Repeats		HVOCs, mg/hp-hr			
			Engine A	Engine B	Engine C	Engine D
FTP-w	3	**Avg**	0.39	3.50	1.79	0.34
		Stdev	0.31	3.61	0.98	0.03
		COV	78.5%	103.1%	54.4%	8.6%
FTP-wo	3	**Avg**	0.93	7.45	1.07	0.45
		Stdev	0.29	11.01	0.73	0.19
		COV	30.9%	147.8%	67.6%	41.0%
CARBx-ICT	2	**Avg**	6.97	2.57	N/A	1.86
		Stdev	4.98	1.76	N/A	0.44
		COV	71.4%	68.5%	N/A	23.9%
CARBz-CH	2	**Avg**	1.29	3.50	N/A	2.28
		Stdev	0.44	0.19	N/A	0.50
		COV	34.3%	5.5%	N/A	22.0%
16-Hour	3	**Avg**	2.87	1.02	0.17	0.95
		Stdev	1.92	0.00	0.29	0.41
		COV	66.8%	0.2%	173.2%	42.8%

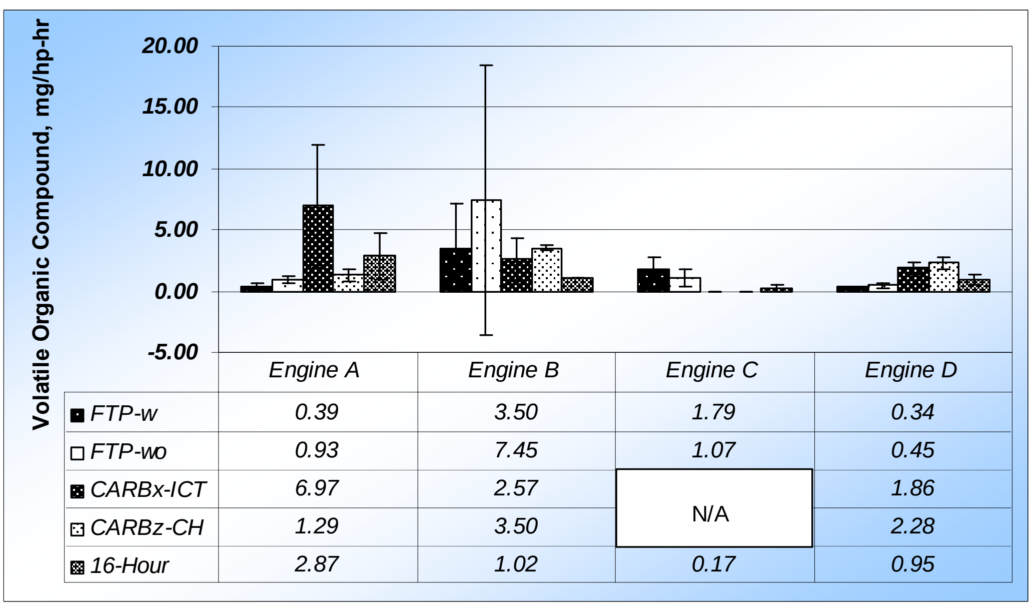


FIGURE 58. AVERAGE SELECTED VOC COMPOUND BRAKE-SPECIFIC EMISSIONS

6.0 SUMMARY

ACES Phase 1 engine testing started in March, 2007, and was completed in August, 2008. Four model year 2007 heavy-duty diesel engines were characterized for regulated and unregulated emissions using different cycles that included the FTP, CARBx-ICT, CARBz-CH, and the 16-Hour transient cycle. A backup engine was characterized for regulated emissions at SwRI's San Antonio, Texas, elevation (barometric pressure of 99.3 kPa) and at a simulated higher elevation (barometric pressure of 82.6 kpa) similar to that at LRRI in Albuquerque, New Mexico.

- Regulated emissions of NMHC, CO, and PM were 95, 98, and 89 percent below the EPA 2007 standard, respectively, and NO_x emissions were 10 percent below the standard.
- Unregulated emissions that included single ring aromatics, PAH, nitroPAH, alkanes, alcohol and organic acids, hopanes/steranes, carbonyls, metals and elements, organic carbon, elemental carbon, and dioxins/furans were 79 to 99 percent lower than the emissions from a similar 2004 technology engine. Inorganic ions were 38 percent lower.
- Average FTP NO_2 to NO_x ratio was 68 percent for the ACES engines, which is higher than the 4 to 15 percent expected in 2004 technology engines. The use of catalyzed aftertreatment devices for PM reduction in 2007 technology engines is causing the temporary increase in NO_2 to NO_x ratio, but in 2010, both the absolute level of NO_2 as well as NO_x emissions must be reduced to meet EPA 2010 NOx standard of 0.20 g/hp-hr, an 83 percent reduction from an average 2007 NOx emission level of 1.2 g/hp-hr.
- Higher elevation led to 34 percent increase in NO_x emissions for the FTP transient cycle.
- Lower exhaust temperature operation led to higher emissions of low and high molecular weight hydrocarbons, mainly due to the lower oxidation rates of the catalyzed aftertreatment systems.
- Average PM emissions with blowy-by was 50 percent higher than the PM emissions without blow-by.
- Average particle number emissions were one to two orders of magnitude lower than from typical 2004 technology engines. Active DPF regeneration events led to a more than one order of magnitude increase in cycle average particle number emissions, even though their occurrence was infrequent.
- Tunnel blank emission levels were similar to the emissions reported for the FTP cycle for many unregulated emissions species. CVS tunnel contamination, and storage and release of materials may impact the results for emissions measurements at extremely low levels. No tunnel blank corrections were performed during this work. Only tunnel background correction was performed when available.

Finally, some selected speciation data that are discussed in the body of the report are included in the designated appendices. All raw data will be transferred to a CRC website at http://www.crcao.org, which will be accessible to the public.

7.0 REFERENCES

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APPENDIX A

HEI REPORT ON ENGINE SELECTION

Health Effects Institute

Report on Engine Selection
June 20, 2008

Engine Selection Process Group

REPORT ON ENGINE SELECTION
Prepared by the Engine Selection Process Group
June 20, 2008

INTRODUCTION

The Advanced Collaborative Emission Study (ACES) is a product stewardship initiative undertaken to characterize the emissions and assess the potential cancer and noncancer effects of the exhaust of heavy heavy-duty diesel engines and control systems designed to meet the 2007 and 2010 standards for particulate matter (PM) and nitrogen oxides (NOx). It is funded by U.S. DOE, U.S. EPA, the Engine Manufacturers Association, California ARB, the American Petroleum Institute, Corning, and the Coordinating Research Council. For this study, four manufacturers (Caterpillar, Cummins, Detroit Diesel, and Volvo) have voluntarily provided 2007-compliant production-ready engines for evaluation of emissions. The identity of the engines is being kept confidential, and the engines have been randomly assigned a letter from A to D.

In Phase 1 of ACES, which is completed, extensive characterization of the gaseous and particulate emissions of the four engines has been conducted at Southwest Research Institute (SwRI). A 16-Hour cycle, developed for use in Phase 3, was also used as one of the test cycles in the emissions characterization. The results from the triplicate 16-hr cycles have been the basis for selecting one heavy heavy-duty diesel engine/aftertreatment system for health testing. In Phase 3, the selected 2007-compliant engine system will be installed in a specially-designed emissions generation and animal exposure facility. Emissions will be characterized in the chambers prior to the engine's use in a chronic inhalation study with health measurements at several time periods. Phase 2 will involve characterization of emissions from 2010-compliant engines.

Phase 1 has been overseen by CRC and its ACES Panel; Phase 3 is overseen by HEI and its ACES Oversight Committee.

In March 2007, HEI set up an Engine Selection Process Group (ESPG) comprising a subset of members of the CRC ACES Panel and HEI ACES Oversight Committee to guide HEI in the process of engine selection. This report provides an overview of the process to develop and finalize the engine selection plan, a brief description of the Final Engine Selection Plan, a summary of the Phase 1 study results and the role of the CRC ACES Panel, and the process by which the ESPG made a recommendation for engine selection.

Attached to this document is the Final Plan for Engine Selection of May 29, 2008 (prepared by the ESPG).

A Summary of Exhaust Species Measurements and Calculations for ACES Phase 1 Engine Selection Process and the tables with emissions rates for all species used in engine selection (prepared by Dr. Imad Khalek of SwRI) are available on a secure web site upon request.

OVERVIEW OF PROCESS TO DEVELOP THE ENGINE SELECTION PLAN

The process by which the ESPG developed and modified the plan is described in the Final Plan for Engine Selection of May 29, 2008. That document represents the second revision of the Initial Draft Plan for Engine Selection (dated September 29, 2007), which was approved by the Steering Committee in October 2007. The first set of modifications to the plan were made in the winter of 2008 and resulted in the Final Initial Plan for Engine Selection of April 11, 2008. These included (1) removing dioxin and furans (which were not analyzed in the 16-Hour cycle for all engines) from the list of components to be used in engine selection, (2) adding chloride (as a potential precursor of dioxin), and (3) adding a new section describing the protocol for engine selection. This document was approved by the ESPG and discussed at the Joint Meeting of the HEI ACES Oversight and Advisory Committees on April 29, 2008.

In establishing the Initial Plan, the ESPG kept the ability to refine it once the actual data became available for review. As described in more detail in the next section, the CRC Panel recommended some minor changes during one of their periodic meetings to review and discuss the results of Phase 1. These were approved by the ESPG and incorporated in the Final Plan for Engine Selection of May 29, 2008. They include: (1) clarifying how to report negative data resulting from background correction; (2) clarifying that total PAHs be referred to as "total PAHs with the exclusion of nitro-and oxygenated PAHs" to avoid double counting of those PAHs, which are in the list of compounds for engine selection on their own; and (3) adding a new rule for removing compounds for which measurements are at or below the LOD in each of the three replicates for three of the four engines. Because the changes made in the two subsequent revisions of the Initial Draft Plan for Engine Selection approved by the ESPG did not substantially alter the principles and rules laid out in the Initial Draft, those documents were not sent to the Steering Committee for approval.

The Initial Plan deferred the decision on all aspects of analyses of the emissions data to the CRC ACES Panel. At the May 7 and 8, 2008 meeting the CRC Panel agreed on the following:

- Background correction will be made for those measurements for which the EPA CFR prescribes such correction and for those exhaust measurements for which background emissions were measured simultaneously.
- Metals measurements will be reported based on the XRF method. Although two methods, XRF and ICP-MS, were used to measure metals, the panel members agreed that the XRF was more sensitive than the ICP-MS method for most metals.
- If no quality issues with the data could be identified, the data would not be removed on the basis of numerical value.

BRIEF DESCRIPTION OF ENGINE SELECTION PLAN

The plan set forth the following general principles:

- The study does not have adequate statistical power to distinguish among engines;
- All selected emission components should have the same weight in the total ranking because their relative toxicity cannot be assessed at low concentrations; and
- It is important to avoid choosing an engine with the lowest overall emissions, because it may lead to questions about effects of emissions from engines with higher overall emissions.

The plan states that the engine selection will use 4 ways of ranking the compounds, one nonparametric and three parametric. Regardless of the method, ranks of individual component or classes of components for each engine are added to obtain an overall score. The highest overall score for each method will have the highest rank (i.e. 4th).

- If 3 or 4 of the methods yield the same 4th ranking engine, that engine will be selected;
- If fewer than 3 methods identify the same 4th ranking engine, the engine would be selected randomly, with the following two caveats:
    - If 3 or 4 of the ranking methods yield the same 1st ranking engine, this engine will not be included in the random selection;

- If an engine is defined as an outlier, it will not be included in the random selection (because it would not be considered representative).

SUMMARY OF PHASE 1 STUDY AND ROLE OF THE CRC ACES PANEL

Phase 1 was carried at SwRI by Dr. Imad Khalek and collaborators at Desert Research Institute. The CRC Panel met regularly during the course of the testing to review and discuss the results of all test cycles (FTP, CARB and combined 16-Hour FTP/CARB cycles) as they became available. The final meeting of the Panel to discuss the 16-Hour emission data to be used for engine selection was held on May 7 and 8 at SwRI. Two members of the HEI Oversight Committee and a member of the HEI staff participated as well. The goal of the meeting was to review all data from the Phase 1 of ACES and clarify any questions about the results, in advance of HEI's ESPG meeting to select the engine.

A large part of the data were presented and reviewed at the CRC ACES Panel meeting. These included all the regulated pollutants, PAHs, carbonyls, and metals for all the cycles. Some of the data were still being processed (ionic inorganic species and EC/OC for engine B) and were not presented. Butadiene was not detected in any of the samples. Most of the data reported were not considered final. It was agreed that Dr. Imad Khalek and his collaborators would continue the data review, focusing on the 16-Hour cycle, and would post the data on an FTP site so all Panel members could review them as well. Once the CRC Panel and Dr. Khalek felt confident that all data transformation steps were right, errors had been corrected, and predetermined rules for eliminating values below the LOD had been applied appropriately, the final average emission rates for each compound and class of compounds for each engine data (see Table 1) were provided to Dr. Robert Mason (the SwRI statistician) for ranking according to the methods described in the Engine Selection Plan. The overall ranking of the four engines is provided in Table 3. The four ranking tables are provided in on pages 7 and 8 of this document.

Table 1. Summary of Emission Rates for Compounds and Classes of Compounds Used for Engine Ranking (6/4/08)

Emissions Components	Engine A	Engine B	Engine C	Engine D	AVG.	St. dev.
NO (g/hp-hr)	0.54	0.48	0.86	0.63	**0.63**	**0.17**
NO_2 (g/hp-hr)	0.95	0.91	0.56	0.56	**0.74**	**0.21**
Carbon Monoxide (g/hp-hr)	0.09	0.08	0.46	0.15	**0.20**	**0.18**
PM Mass (g/hp-hr)	0.0013	0.0012	0.0011	0.0013	**0.0012**	**0.0001**
PM Number (Part./hp-hr)	4.13E+13	5.67E+13	1.66E+13	2.38E+13	**3.46E+13**	**1.80E+13**
EC (mg/hp-hr)	0.20	0.27	0.26	0.22	**0.24**	**0.03**
OC (mg/hp-hr)	1.53	0.24	0.26	0.52	**0.64**	**0.61**
Total Metals (by XRF) (µg/hp-hr)	62.37	62.15	28.88	89.91	**60.82**	**24.97**
Inorganic Ionic Species (mg/hp-hr)	3.84	3.09	2.86	2.47	**3.06**	**0.57**
Carbonyl compounds (mg/hp-hr)	4.99	1.64	4.40	2.44	**3.37**	**1.59**
Single ring aromatic compounds (mg/hp-hr)	0.35	1.20	0.81	0.69	**0.76**	**0.35**
Total PAHs (mg/hp-hr)	0.55	0.73	0.84	0.80	**0.73**	**0.13**
Total Nitro PAHs (µg/hp-hr)	0.44	0.77	0.86	0.58	**0.66**	**0.19**
Total oxygenated PAHs (µg/hp-hr)	6.25	5.96	3.76	3.29	**4.82**	**1.51**
Nitrosamines (µg/hp-hr)	32.54	28.06	52.89	25.82	**34.83**	**12.36**

MEETING OF THE ESPG TO SELECT THE ENGINE

On June 6, 2008, the ESPG met at HEI to review the final set of data and select the engine for Phase 3 based on the final ranking of the four engines. The list of all ESPG members and those who participated is provided in Table 2. Other participants included: Robert Mason (SwRI) and members of the HEI staff (Maria Costantini, Daniel Greenbaum, Robert O'Keefe, and Annemoon van Erp).

Table 2. List of ESPG members at the June 6 meeting

	Present	On the phone
Reynaldo Agama, Caterpillar	Y	
James Ball, Ford	N	
Melvyn Branch, HEI Oversight Committee	N	
Steve Cadle (retired), representing General Motors	Y	
Kenneth Demerjian, HEI Oversight Committee	N	
Timothy French, EMA		Y
Helmut Greim, HEI Oversight Committee	N	
Thomas Hesterberg, International	N	
Donald Keski-Hynnila, Detroit Diesel	Y	
David Kittelson, HEI Oversight Committee	Y	
Douglas Lawson, NREL	Y	
Hector Maldonado, CARB		Y
Mani Natarajan, Marathon Petroleum Co	N	
Howard Rockette, HEI Oversight Committee	Y	
Shirish Shimpi, Cummins	Y	
Joseph Somers, EPA	Y	
Chris Tennant, CRC	Y	
Mark Utell (Chair), HEI Oversight Committee	Y	
Urban Wass, Volvo	N	Y
Kenneth Wright, Conoco Phillips	Y	

The meeting started with an overview of the results of Phase 1 by Dr. Tennant. He explained how the 16-Hour cycle was selected and developed and noted that it was designed to capture a cold start. Regeneration occurred at least once during the 16-Hour cycle. For this testing, the CVS was also connected to an exposure chamber (without animals). Most of the measurements were made in samples taken from the CVS, but some (EC, OC, and PM number) were made in samples taken from the exposure chamber. The emission rates of the regulated pollutants were well below the 2007 standards. For a few species (CO, EC, toluene, and iron) an unusual variance was noted that could not be explained by issues in sample collection or analyses.

The ESPG members noted that both EC and OC were higher than the PM filter mass. This could have been due to the fact that they were measured in the chamber while the PM mass was measured in the CVS or to artifacts in collecting PM on a filter. Another observation was that the mass of total inorganic ions was higher than that of the PM filter mass. This could not be explained. The ESPG decided to leave this class of compounds in the list because, even if there were an error, it appeared to be systematic and thus was unlikely to bias the engine selection. The ESPG noted that two engines had higher NO_2 emissions (A and B) compared to the other two (C and D) and that, if an engine with higher NO_2 were selected, its exhaust may need to be diluted more. With regard to elements, the ESPG was surprised to find that sodium was the most abundant one. It was not clear whether sodium was a contaminant or whether it was coming from lube oil. In the absence of a valid reason for removing this element, it was left in the list.

Dr. Mason summarized how the measurements below the LOD had been treated based on the rules set in the Final Engine Selection Plan. He noted that chloride was the only species removed because for at least 3 engines, all three measurements were below the LOD. He also explained that none of the engines met the criteria for being defined as an outlier. The results supported the initial hypotheses that no engine had higher or lower emissions for all the components than the other engines. Dr. Rockette (the biostatistician of the ESPG) applied two tests that are used to determine whether there are differences among groups of measurements (Friedman's two-way analysis of variance and ANOVA). The tests did not show statistically significant differences among the four engines, although the small number of samples limited the ability to detect a difference even if one did exist.

The ESPG noted that the results show that, based on the engine selection rules, there is little or no difference in the total ranking among the engines, but one of the four engines (D) did happen to rank lowest in all four ranking methods (see Table 3). This finding excluded this engine from being included in the random selection. The ranking of the other three engines changed depending on the ranking method used and no engine was ranked highest with at least three of the four ranking methods.

Table 3. Summary of total ranking (6/4/2008)

	Engine A	Engine B	Engine C	Engine D
Method 1	40.5	36.0	39.5	34.0
Method 2a	15.96	14.83	15.89	13.33
Method 2b	59.31	60.12	60.12	54.61
Method 2c	0.77	1.58	1.58	-3.93

Highest
Lowest

Some ESPG members expressed concern about the fact that two of the four ranking methods (2b – which corrects by the standard deviation, and 2c – which corrects by the mean and the standard deviation) give rise to exactly the same rank order among the four engines and only one should have been used. However, all ESPG members agreed that the group should not create new rules *post-hoc*. Dr. Mason commented that, if one used only method 1 (which ranks the data from lowest to highest and ignores the actual values) and 2c (which is the most common standardization method and uses both the mean and the standard deviation) the results would not change.

Given the ranking results, the ESPG – including the representatives of all four engine manufacturers – agreed that the selection should be random among engines A, B, and C. This was done by random drawing by Dr. Mark Utell, Chair of the HEI Research Committee. The engine that was randomly selected was Engine B; hence the ESPG recommends that Engine B be used for Phase 3.

RANKING TABLES

Ranking Method 1

6/4/08	Engine A		Engine B		Engine C		Engine D		
Emissions Components	**Emissions**	**Rank**	**Emissions**	**Rank**	**Emissions**	**Rank**	**Emissions**	**Rank**	**Total Rankings**
NO, g/hp-hr	0.54	2.0	0.48	1.0	0.86	4.0	0.63	3.0	10.0
NO2, g/hp-hr	0.95	4.0	0.91	3.0	0.56	1.5	0.56	1.5	10.0
Carbon Monoxide, g/hp-hr	0.09	2.0	0.08	1.0	0.46	4.0	0.15	3.0	10.0
PM Mass, g/hp-hr	0.0013	3.5	0.0012	2.0	0.0011	1.0	0.0013	3.5	10.0
PM Number, Part./hp-hr	4.13E+13	3.0	5.67E+13	4.0	1.66E+13	1.0	2.38E+13	2.0	10.0
EC (mg/hp-hr)	0.20	1.0	0.27	4.0	0.26	3.0	0.22	2.0	10.0
OC (mg/hp-hr)	1.53	4.0	0.24	1.0	0.26	2.0	0.52	3.0	10.0
Total Metals, mg/hp-hr	62.37	3.0	62.15	2.0	28.88	1.0	89.91	4.0	10.0
Inorganic Ionic Species, mg/hp-hr	3.84	4.0	3.09	3.0	2.86	2.0	2.47	1.0	10.0
Carbonyl compounds (mg/hp-hr)	4.99	4.0	1.64	1.0	4.40	3.0	2.44	2.0	10.0
Single ring aromatic compounds, mg/hp-hr	0.35	1.0	1.20	4.0	0.81	3.0	0.69	2.0	10.0
Total PAHs (mg/hp-hr)	0.55	1.0	0.73	2.0	0.84	4.0	0.80	3.0	10.0
Total Nitro PAHs (µg/hp-hr)	0.44	1.0	0.77	3.0	0.86	4.0	0.58	2.0	10.0
Total oxygenated PAHs (µg/hp-hr)	6.25	4.0	5.96	3.0	3.76	2.0	3.29	1.0	10.0
Nitrosamines (µg/hp-hr)	32.54	3.0	28.06	2.0	52.89	4.0	25.82	1.0	10.0
Total Ranking		40.5		36.0		39.5		34.0	

Ranking Method 2a

6/4/08	Engine A		Engine B		Engine C		Engine D		
Emissions Components	**Emissions**	**Rank**	**Emissions**	**Rank**	**Emissions**	**Rank**	**Emissions**	**Rank**	**Mean of 4 Engines**
NO, g/hp-hr	0.54	0.86	0.48	0.76	0.86	1.37	0.63	1.00	0.63
NO2, g/hp-hr	0.95	1.28	0.91	1.22	0.56	0.75	0.56	0.75	0.75
Carbon Monoxide, g/hp-hr	0.09	0.46	0.08	0.41	0.46	2.36	0.15	0.77	0.20
PM Mass, g/hp-hr	0.0013	1.06	0.0012	0.98	0.0011	0.90	0.0013	1.06	0.0012
PM Number, Part./hp-hr	4.13E+13	1.19	5.67E+13	1.64	1.66E+13	0.48	2.38E+13	0.69	3.46E+13
EC (mg/hp-hr)	0.20	0.84	0.27	1.14	0.26	1.09	0.22	0.93	0.24
OC (mg/hp-hr)	1.53	2.40	0.24	0.38	0.26	0.41	0.52	0.82	0.64
Total Metals, mg/hp-hr	62.37	1.03	62.15	1.02	28.88	0.47	89.91	1.48	60.83
Inorganic Ionic Species, mg/hp-hr	3.84	1.25	3.09	1.01	2.86	0.93	2.47	0.81	3.07
Carbonyl compounds (mg/hp-hr)	4.99	1.48	1.64	0.49	4.40	1.31	2.44	0.72	3.37
single ring aromatic compounds, mg/hp-hr	0.35	0.46	1.20	1.57	0.81	1.06	0.69	0.90	0.76
Total PAHs (mg/hp-hr)	0.55	0.75	0.73	1.00	0.84	1.15	0.80	1.10	0.73
Total Nitro PAHs (µg/hp-hr)	0.44	0.66	0.77	1.16	0.86	1.30	0.58	0.88	0.66
Total oxygenated PAHs (µg/hp-hr)	6.25	1.30	5.96	1.24	3.76	0.78	3.29	0.68	4.82
Nitrosamines (µg/hp-hr)	32.54	0.93	28.06	0.81	52.89	1.52	25.82	0.74	34.83
Total Ranking		15.96		14.83		15.89		13.33	

Ranking Method 2b

6/4/08	Engine A		Engine B		Engine C		Engine D		
Emissions Components	**Emissions**	**Rank**	**Emissions**	**Rank**	**Emissions**	**Rank**	**Emissions**	**Rank**	**Std. Dev. Of 4 Engines**
NO, g/hp-hr	0.54	3.24	0.48	2.88	0.86	5.16	0.63	3.78	0.17
NO2, g/hp-hr	0.95	4.43	0.91	4.25	0.56	2.61	0.56	2.61	0.21
Carbon Monoxide, g/hp-hr	0.09	0.50	0.08	0.45	0.46	2.56	0.15	0.84	0.18
PM Mass, g/hp-hr	0.0013	13.58	0.0012	12.53	0.0011	11.49	0.0013	13.58	0.0001
PM Number, Part./hp-hr	4.13E+13	2.29	5.67E+13	3.15	1.66E+13	0.92	2.38E+13	1.32	1.80E+13
EC (mg/hp-hr)	0.20	6.05	0.27	8.17	0.26	7.87	0.22	6.66	0.03
OC (mg/hp-hr)	1.53	2.51	0.24	0.39	0.26	0.43	0.52	0.85	0.61
Total Metals, mg/hp-hr	62.37	2.50	62.15	2.49	28.88	1.16	89.91	3.60	24.97
Inorganic Ionic Species, mg/hp-hr	3.84	6.66	3.09	5.36	2.86	4.96	2.47	4.28	0.58
Carbonyl compounds (mg/hp-hr)	4.99	3.15	1.64	1.03	4.40	2.77	2.44	1.54	1.59
single ring aromatic compounds, mg/hp-hr	0.35	1.00	1.20	3.42	0.81	2.31	0.69	1.97	0.35
Total PAHs (mg/hp-hr)	0.55	4.29	0.73	5.69	0.84	6.55	0.80	6.23	0.13
Total Nitro PAHs (µg/hp-hr)	0.44	2.33	0.77	4.08	0.86	4.56	0.58	3.07	0.19
Total oxygenated PAHs (µg/hp-hr)	6.25	4.15	5.96	3.96	3.76	2.50	3.29	2.18	1.51
Nitrosamines (µg/hp-hr)	32.54	2.63	28.06	2.27	52.89	4.28	25.82	2.09	12.36
Total Ranking		59.31		60.12		60.12		54.61	

Ranking Method 2c

6/4/08	Engine A		Engine B		Engine C		Engine D			
Emissions Components	**Emissions**	**Rank**	**Emissions**	**Rank**	**Emissions**	**Rank**	**Emissions**	**Rank**	**Mean of 4 Engines**	**Std. Dev. Of 4 Engines**
NO, g/hp-hr	0.54	-0.52	0.48	-0.88	0.86	1.39	0.63	0.01	0.63	0.17
NO2, g/hp-hr	0.95	0.96	0.91	0.77	0.56	-0.86	0.56	-0.86	0.75	0.21
Carbon Monoxide, g/hp-hr	0.09	-0.59	0.08	-0.64	0.46	1.48	0.15	-0.25	0.20	0.18
PM Mass, g/hp-hr	0.0013	0.78	0.0012	-0.26	0.0011	-1.31	0.0013	0.78	0.0012	0.00
PM Number, Part./hp-hr	4.13E+13	0.37	5.67E+13	1.23	1.66E+13	-1.00	2.38E+13	-0.60	3.46E+13	1.80E+13
EC (mg/hp-hr)	0.20	-1.13	0.27	0.98	0.26	0.68	0.22	-0.53	0.24	0.03
OC (mg/hp-hr)	1.53	1.47	0.24	-0.65	0.26	-0.62	0.52	-0.19	0.64	0.61
Total Metals, mg/hp-hr	62.37	0.06	62.15	0.05	28.88	-1.28	89.91	1.16	60.83	24.97
Inorganic Ionic Species, mg/hp-hr	3.84	1.34	3.09	0.04	2.86	-0.36	2.47	-1.03	3.07	0.58
Carbonyl compounds (mg/hp-hr)	4.99	1.02	1.64	-1.09	4.40	0.65	2.44	-0.58	3.37	1.59
single ring aromatic compounds, mg/hp-hr	0.35	-1.18	1.20	1.25	0.81	0.14	0.69	-0.21	0.76	0.35
Total PAHs (mg/hp-hr)	0.55	-1.40	0.73	0.00	0.84	0.86	0.80	0.55	0.73	0.13
Total Nitro PAHs (µg/hp-hr)	0.44	-1.18	0.77	0.57	0.86	1.05	0.58	-0.44	0.66	0.19
Total oxygenated PAHs (µg/hp-hr)	6.25	0.95	5.96	0.76	3.76	-0.70	3.29	-1.01	4.82	1.51
Nitrosamines (µg/hp-hr)	32.54	-0.19	28.06	-0.55	52.89	1.46	25.82	-0.73	34.83	12.36
Total Ranking		0.77		1.58		1.58		-3.93		

APPENDIX B

ADDITIONAL ABBREVIATIONS LIST

Polycyclic Aromatic Hydrocarbons

NAPHTH	Naphthalene
NAPHTHU	Naphthalene uncertainty
QUINOLINE	Quinoline
QUINOLINEU	Quinoline uncertainty
MNAPH2	2-methylnaphthalene
MNAPH2U	2-Methylnaphthalene uncertainty
MNAPH1	1-Methylnaphthalene
MNAPH1U	1-Methylnaphthalene uncertainty
BIPHEN	Biphenyl
BIPHENU	Biphenyl uncertainty
ENAP12	1+2Ethylnaphthalene
ENAP12U	1+2Ethylnaphthalene uncertainty
M_2BPH	2-Methylbiphenyl
M_2BPHU	2-Methylbiphenyl uncertainty
DMN267	2,6+2,7-Dimethylnaphthalene
DMN267U	2,6+2,7-Dimethylnaphthalene uncertainty
DM1367	1,3+1,6+1,7-Dimethylnaphthalene
DM1367U	1,3+1,6+1,7-Dimethylnaphth uncertainty
D14523	1,4+1,5+2,3-Dimethylnaphthalene
D14523U	1,4+1,5+2,3-Dimethylnaphth uncertainty
ACNAPY	Acenaphthylene
ACNAPYU	Acenaphthylene uncertainty
DMN12	1,2-Dimethylnaphthalene
DMN12U	1,2-Dimethylnaphthalene uncertainty
DMN18	1,8-Dimethylnaphthalene
DMN18U	1,8-Dimethylnaphthalene uncertainty
ACNAPE	Acenaphthene
ACNAPEU	Acenaphthene uncertainty
M_3BPH	3-Methylbiphenyl
M_3BPHU	3-Methylbiphenyl uncertainty
M_4BPH	4-Methylbiphenyl
M_4BPHU	4-Methylbiphenyl uncertainty
DBZFUR	Dibenzofuran
DBZFURU	Dibenzofuran uncertainty
EM_12N	1-ethyl-2-methylnaphthalene
EM_12NU	1-ethyl-2-methylnaphthalene uncertainty
TMI235N	2,3,5+I-trimethylnaphthalene
TMI235NU	2,3,5+I-trimethylnaphthalene uncertainty
BTMNAP	B-Trimethylnaphthalene
BTMNAPU	B-Trimethylnaphthalene uncertainty
ATMNAP	A-Trimethylnaphthalene
ATMNAPU	A-Trimethylnaphthalene uncertainty
CTMNAP	C-Trimethylnaphthalene
CTMNAPU	C-Trimethylnaphthalene uncertainty
EM_21N	2-Ethyl-1-methylnaphthalene
EM_21NU	2-Ethyl-1-methylnaphthalene uncertainty

ETMNAP	E-Trimethylnaphthalene
ETMNAPU	E-Trimethylnaphthalene uncertainty
TM245N	2,4,5-Trimethylnaphthalene
TM245NU	2,4,5-Trimethylnaphthalene uncertainty
FTMNAP	F-Trimethylnaphthalene
FTMNAPU	F-Trimethylnaphthalene uncertainty
FLUORE	Fluorene
FLUOREU	Fluorene uncertainty
TM145N	1,4,5-Trimethylnaphthalene
TM145NU	1,4,5-Trimethylnaphthalene uncertainty
JTMNAP	J-Trimethylnaphthalene
JTMNAPU	J-Trimethylnaphthalene uncertainty
A_MFLUO	A-Methylfluorene
A_MFLUOU	A-Methylfluorene uncertainty
B_MFLUO	B-Methylfluorene
B_MFLUOU	B-Methylfluorene uncertainty
M_1FLUO	1-Methylfluorene
M_1FLUOU	1-Methylfluorene uncertainty
DBTH	Dibenzothiophene
DBTHU	Dibenzothiophene uncertainty
PHENAN	Phenanthrene
PHENANU	Phenanthrene uncertainty
ANTHRA	Anthracene
ANTHRAU	Anthracene uncertainty
ACQUONE	Acenaphthenequinone
ACQUONEU	Acenaphthenequinone uncertainty
M_2PHEN	3-Methylphenanthrene
M_2PHENU	3-Methylphenanthrene uncertainty
M_3PHEN	2-Methylphenanthrene
M_3PHENU	2-Methylphenanthrene uncertainty
M_2ANTH	2-Methylanthracene
M_2ANTHU	2-Methylanthracene uncertainty
M_45PHEN	4,5-Methylenephenanthrene
M_45PHENU	4,5-Methylenephenanthrene uncertainty
M_9PHEN	9-Methylphenanthrene
M_9PHENU	9-Methylphenanthrene uncertainty
MPHT_1	1-Methylphenanthrene
MPHT_1U	1-Methylphenanthrene uncertainty
DBPHT	Dibutyl phthalate
DBPHTU	Dibutyl phthalate uncertainty
ANTHRON	Anthrone
ANTHRONU	Anthrone uncertainty
M_9ANT	9-Methylanthracene
M_9ANTU	9-Methylanthracene uncertainty
NAP2PHEN	2-Phenylnaphthalene
NAP2PHENU	2-Phenylnaphthalene uncertainty
A_DMPH	A-Dimethylphenanthrene
A_DMPHU	A-Dimethylphenanthrene uncertainty

B_DMPH	B-Dimethylphenanthrene
B_DMPHU	B-Dimethylphenanthrene uncertainty
DM17PH	1,7-Dimethylphenanthrene
DM17PHU	1,7-Dimethylphenanthrene uncertainty
DM36PH	3,6-Dimethylphenanthrene
DM36PHU	3,6-Dimethylphenanthrene uncertainty
D_DMPH	D-Dimethylphenanthrene
D_DMPHU	D-Dimethylphenanthrene uncertainty
E_DMPH	E-Dimethylphenanthrene
E_DMPHU	E-Dimethylphenanthrene uncertainty
C_DMPH	C-Dimethylphenanthrene
C_DMPHU	C-Dimethylphenanthrene uncertainty
FLUORA	Fluoranthene
FLUORAU	Fluoranthene uncertainty
PYRENE	Pyrene
PYRENEU	Pyrene uncertainty
RETENE	Retene
RETENEU	Retene uncertainty
BAFLUO	Benzo(a)fluorene
BAFLUOU	Benzo(a)fluorene uncertainty
BBFLUO	Benzo(b)fluorene
BBFLUOU	Benzo(b)fluorene uncertainty
BMPYFL	B-MePy/MeFl
BMPYFLU	B-MePy/MeFl uncertainty
C1MFLPY	1-MeFl+C-MeFl/Py
C1MFLPYU	1-MeFl+C-MeFl/Py uncertainty
M_13FL	1+3-methylfluoranthene
M_13FLU	1+3-methylfluoranthene uncertainty
M_4PYR	4-methylpyrene
M_4PYRU	4-methylpyrene uncertainty
CMPYFL	C-MePy/MeFl
CMPYFLU	C-MePy/MeFl uncertainty
DMPYFL	D-MePy/MeFl
DMPYFLU	D-MePy/MeFl uncertainty
M_1PYR	1-Methylpyrene
M_1PYRU	1-Methylpyrene uncertainty
BNTIOP	Benzonaphthothiophene
BNTIOPU	Benzonaphthothiophene uncertainty
BZCPHEN	Benzo(c)phenanthrene
BZCPHENU	Benzo(c)phenanthrene uncertainty
BGHIFL	Benzo(ghi)fluoranthene
BGHIFLU	Benzo(ghi)fluoranthene uncertainty
PHANT9	9-Phenylanthracene
PHANT9U	9-Phenylanthracene uncertainty
CP_CDPYR	Cyclopenta(c,d)pyrene
CP_CDPYRU	Cyclopenta(c,d)pyrene uncertainty
BAANTH	Benz(a)anthracene
BAANTHU	Benz(a)anthracene uncertainty

CHR_TR	Chrysene-Triphenylene
CHR_TRU	Chrysene-Triphenylene uncertainty
B2EPHT	Bis[2-ethylhexyl]phthalate
B2EPHTU	Bis[2-ethylhexyl]phthalate uncertainty
M_3CHR	3-Methylchrysene
M_3CHRU	3-Methylchrysene uncertainty
CHRY56M	5+6-Methylchrysene
CHRY56MU	5+6-Methylchrysene uncertainty
M_7BAA	7-Methylbenz(a)anthracene
M_7BAAU	7-Methylbenz(a)anthracene uncertainty
DMBAN712	7,12-Dimethylbenz(a)anthracene
DMBAN712U	7,12-Dimethylbenz(a)anthracene uncertainty
BBJKFL	Benzo(b+j+k)fluoranthene
BBJKFLU	Benzo(b+j+k)fluoranthene uncertainty
BAFL	Benzo(a)fluoranthene
BAFLU	Benzo(a)fluoranthene uncertainty
BEPYRN	Benzo(e)pyrene
BEPYRNU	Benzo(e)pyrene uncertainty
BAPYRN	Benzo(a)pyrene
BAPYRNU	Benzo(a)pyrene uncertainty
PERYLE	Perylene
PERYLEU	Perylene uncertainty
MCHOL3	3-Methylcholanthrene
MCHOL3U	3-Methylcholanthrene uncertainty
M_7BPY	7-Methylbenzo(a)pyrene
M_7BPYU	7-Methylbenzo(a)pyrene uncertainty
INCDFL	Indeno[123-cd]fluoranthene
INCDFLU	Indeno[123-cd]fluoranthene uncertainty
DBAHACR	Dibenz(a,h)acridine
DBAHACRU	Dibenz(a,h)acridine uncertainty
DBAJACR	Dibenz(a,j)acridine
DBAJACRU	Dibenz(a,j)acridine uncertainty
IN123PYR	Indeno[123-cd]pyrene
IN123PYRU	Indeno[123-cd]pyrene uncertainty
DBAJAN	Dibenzo(a,j)anthracene
DBAJANU	Dibenzo(a,j)anthracene uncertainty
DBAHACAN	Dibenzo(ah+ac)anthracene
DBAHACANU	Dibenzo(ah+ac)anthracene uncertainty
BBCHR	Benzo(b)chrysene
BBCHRU	Benzo(b)chrysene uncertainty
PIC	Picene
PICU	Picene uncertainty
DBCGCAR	7H-dibenzo[c,g]carbazole
DBCGCARU	7H-dibenzo[c,g]carbazole uncertainty
BGHIPE	Benzo(ghi)perylene
BGHIPEU	Benzo(ghi)perylene uncertainty
ANTHAN	Anthanthrene
ANTHANU	Anthanthrene uncertainty

DBALPYR	Dibenzo(a,l)pyrene
DBALPYRU	Dibenzo(a,l)pyrene uncertainty
DBAEPYR	Dibenzo(a,e)pyrene
DBAEPYRU	Dibenzo(a,e)pyrene uncertainty
CORONE	Coronene
CORONEU	Coronene uncertainty
DBAIPYR	Dibenzo(a,i)pyrene
DBAIPYRU	Dibenzo(a,i)pyrene uncertainty
DBAHPYR	Dibenzo(a,h)pyrene
DBAHPYRU	Dibenzo(a,h)pyrene uncertainty
DBBKFL	Dibenzo(b,k)fluoranthene
DBBKFLU	Dibenzo(b,k)fluoranthene uncertainty

Oxygenated PAHs

FL9ONE	9-Fluorenone
FL9ONEU	9-Fluorenone uncertainty
XANONE	Xanthone
XANONEU	Xanthone uncertainty
PNAPONE	Perinaphthenone
PNAPONEU	Perinaphthenone uncertainty
ANTHRON	Anthrone
ANTHRONU	Anthrone uncertainty
ANRQUONE	Anthraquinone
ANRQUONEU	Anthraquinone uncertainty
ANTAL9	9-Anthraaldehyde
ANTAL9U	9-Anthraaldehyde uncertainty
BZANTHR	Benzanthrone
BZANTHRU	Benzanthrone uncertainty
BAA7_12	Benz(a)anthracene-7,12-dione
BAA7_12U	Benz(a)anthracene-7,12-dione uncertainty
BPY910DIH	9,10-dihydrobenzo(a)pyrene-7(8H)-one
BPY910DIHU	9,10-dihydrobenzo(a)pyrene-7(8H)-one uncertainty

Nitrogenated PAHs

NI4PHOL	4-Nitrophenol
NI4PHOLU	4-Nitrophenol uncertainty
NI1NAPTH	1-Nitronaphthalene
NI1NAPTHU	1-Nitronaphthalene uncertainty
NI1ME5N	1-Methyl-5-nitronaphthalene
NI1ME5NU	1-Methyl-5-nitronaphthalene uncertainty
NI2NAPTH	2-Nitronaphthalene
NI2NAPTHU	2-Nitronaphthalene uncertainty
NI2BIPH	2-Nitrobiphenyl
NI2BIPHU	2-Nitrobiphenyl uncertainty
NI4ME2N	2-Methyl-4-nitronaphthalene
NI4ME2NU	2-Methyl-4-nitronaphthalene uncertainty

NI4ME1N	1-Methyl-4-nitronaphthalene
NI4ME1NU	1-Methyl-4-nitronaphthalene uncertainty
MXNIYNAP	x-Methyl-y-nitronaphthalene
MXNIYNAPU	x-Methyl-y-nitronaphthalene uncertainty
NI6ME1N	1-Methyl-6-nitronaphthalene
NI6ME1NU	1-Methyl-6-nitronaphthalene uncertainty
NI3BIPH	3-Nitrobiphenyl
NI3BIPHU	3-Nitrobiphenyl uncertainty
NI4BPH	4-Nitrobiphenyl
NI4BPHU	4-Nitrobiphenyl uncertainty
NI13NAP	1,3-Dinitronaphthalene
NI13NAPU	1,3-Dinitronaphthalene uncertainty
NI15NAP	1,5-Dinitronaphthalene
NI15NAPU	1,5-Dinitronaphthalene uncertainty
NI5ACEN	5-Nitroacenaphthene
NI5ACENU	5-Nitroacenaphthene uncertainty
NI2FLUO	2-Nitrofluorene
NI2FLUOU	2-Nitrofluorene uncertainty
NI4PHEN	4-Nitrophenanthrene
NI4PHENU	4-Nitrophenanthrene uncertainty
NI9ANTHR	9-Nitroanthracene
NI9ANTHRU	9-Nitroanthracene uncertainty
NI9PHEN	9-Nitrophenanthrene
NI9PHENU	9-Nitrophenanthrene uncertainty
NI18NAP	1,8-Dinitronaphthalene
NI18NAPU	1,8-Dinitronaphthalene uncertainty
NI3PHEN	3-Nitrophenanthrene
NI3PHENU	3-Nitrophenanthrene uncertainty
NI2PHEN	2-Nitrophenanthrene
NI2PHENU	2-Nitrophenanthrene uncertainty
NI2ANTHR	2-Nitroanthracene
NI2ANTHRU	2-Nitroanthracene uncertainty
NI1FLUOR	1-Nitrofluoranthene
NI1FLUORU	1-Nitrofluoranthene uncertainty
NI7FLUOR	7-Nitrofluoranthene
NI7FLUORU	7-Nitrofluoranthene uncertainty
NI2FLUOR	2-Nitrofluoranthene
NI2FLUORU	2-Nitrofluoranthene uncertainty
NI3FLUOR	3-Nitrofluoranthene
NI3FLUORU	3-Nitrofluoranthene uncertainty
NI4PYRE	4-Nitropyrene
NI4PYREU	4-Nitropyrene uncertainty
NI8FLUOR	8-Nitrofluoranthene
NI8FLUORU	8-Nitrofluoranthene uncertainty
NI1PYRE	1-Nitropyrene
NI1PYREU	1-Nitropyrene uncertainty
NI2PYRE	2-Nitropyrene
NI2PYREU	2-Nitropyrene uncertainty

NI27FLUO	2,7-Dinitrofluorene
NI27FLUOU	2,7-Dinitrofluorene uncertainty
NI27FL9ON	2,7-Dinitrofluoren-9-one
NI27FL9ONU	2,7-Dinitrofluoren-9-one uncertainty
NI7BZANTH	7-Nitrobenz(a)anthracene
NI7BZANTHU	7-Nitrobenz(a)anthracene uncertainty
NI6CHRY	6-Nitrochrysene
NI6CHRYU	6-Nitrochrysene uncertainty
NI3BZANTH	3-Nitrobenzanthrone
NI3BZANTHU	3-Nitrobenzanthrone uncertainty
NI13PYR	1,3-Dinitropyrene
NI13PYRU	1,3-Dinitropyrene uncertainty
DNIFLUORA	A-Dinitrofluoranthene
DNIFLUORAU	A-Dinitrofluoranthene uncertainty
NI16PYR	1,6-Dinitropyrene
NI16PYRU	1,6-Dinitropyrene uncertainty
NI18PYR	1,8-Dinitropyrene
NI18PYRU	1,8-Dinitropyrene uncertainty
DNIFLUORB	B-Dinitrofluoranthene
DNIFLUORBU	B-Dinitrofluoranthene uncertainty
DNIFLUORC	C-Dinitrofluoranthene
DNIFLUORCU	C-Dinitrofluoranthene uncertainty
NI6A3EBP	6a+3e-nitrobenzpyrene
NI6A3EBPU	a+3e-nitrobenzpyrene uncertainty
NI1BEP	1-nitrobenzo[e]pyrene
NI1BEPU	1-nitrobenzo[e]pyrene uncertainty

<u>Polar Compounds</u>

PHENOL	Phenol
PHENOLU	Phenol uncertainty
HEXAC	Hexanoic acid (c6)
HEXACU	Hexanoic acid (c6) uncertainty
OCRESOL	o-Cresol
OCRESOLU	o-Cresol uncertainty
MCRESOL	m-Cresol
MCRESOLU	m-Cresol uncertainty
PCRESOL	p-Cresol
PCRESOLU	p-Cresol uncertainty
HEPTAC	Heptanoic acid (c7)
HEPTACU	Heptanoic acid (c7) uncertainty
ANILINE	Aniline
ANILINEU	Aniline uncertainty
BENAC	Benzoic acid
BENACU	Benzoic acid uncertainty
OCTANAC	Octanoic acid (c8)
OCTANACU	Octanoic acid (c8) uncertainty
OTOLUIC	o-Toluic

OTOLUICU	o-Toluic uncertainty
MTOLUIC	m-Toluic
MTOLUICU	m-Toluic uncertainty
NONAC	Nonanoic acid (c9)
NONACU	Nonanoic acid (c9) uncertainty
PTOLUIC	p-Toluic
PTOLUICU	p-Toluic uncertainty
DECAC	Decanoic acid (c10)
DECACU	Decanoic acid (c10) uncertainty
UNDECAC	Undecanoic acid (c11)
UNDECACU	Undecanoic acid (c11) uncertainty
LAUAC	Dodecanoic (lauric) acid (c12)
LAUACU	Dodecanoic (lauric) acid (c12) uncertainty
TDECAC	Tridecanoic acid (c13)
TDECACU	Tridecanoic acid (c13) uncertainty
MYRAC	Myristic acid (c14)
MYRACU	Myristic acid (c14) uncertainty
PDECAC	Pentadecanoic acid (c15)
PDECACU	Pentadecanoic acid (c15) uncertainty
PALAC	Palmitic acid (c16)
PALACU	Palmitic acid (c16) uncertainty
HEPTADAC	Heptadecanoic acid (c17)
HEPTADACU	Heptadecanoic acid (c17) uncertainty
OLAC	Oleic acid
OLACU	Oleic acid uncertainty
STEAC	Stearic acid (c18)
STEACU	Stearic acid (c18) uncertainty
NDECAC	Nonadecanoic acid (c19)
NDECACU	Nonadecanoic acid (c19) uncertainty
ECOSAC	Eicosanoic acid (c20)
ECOSACU	Eicosanoic acid (c20) uncertainty
OCTDECDI	Octadecanedioic acid
OCTDECDIU	Octadecanedioic acid uncertainty

Alkanes

NORFARN	Norfarnesane
NORFARNU	Norfarnesane uncertainty
DODEC	Dodecane
DODECU	Dodecane uncertainty
TRIDEC	Tridecane
TRIDECU	Tridecane uncertainty
HPYCYHX	Heptylcyclohexane
HPYCYHXU	Heptylcyclohexane uncertainty
FARNES	Farnesane
FARNESU	Farnesane uncertainty
TDEC	Tetradecane
TDECU	Tetradecane uncertainty

OCYCYHX	Octylcyclohexane
OCYCYHXU	Octylcyclohexane uncertainty
PENTAD	Pentadecane
PENTADU	Pentadecane uncertainty
NOYCYHX	Nonylcyclohexane
NOYCYHXU	Nonylcyclohexane uncertainty
HEXAD	Hexadecane
HEXADU	Hexadecane uncertainty
NORPRST	Norpristane
NORPRSTU	Norpristane uncertainty
DECYHX	Decylcyclohexane
DECYHXU	Decylcyclohexane uncertainty
HEPTAD	Heptadecane
HEPTADU	Heptadecane uncertainty
HEPTDPRIS	Heptadecane_Pristane
HEPTDPRISU	Heptadecane_Pristane uncertainty
DEC1YHX	Undecylcyclohexane
DEC1YHXU	Undecylcyclohexane uncertainty
OCTAD	Octadecane
OCTADU	Octadecane uncertainty
PHYTAN	Phytane
PHYTANU	Phytane uncertainty
DEC2YHX	Dodecylcyclohexane
DEC2YHXU	Dodecylcyclohexane uncertainty
NONAD	Nonadecane
NONADU	Nonadecane uncertainty
DEC3YHX	Tridecylcyclohexane
DEC3YHXU	Tridecylcyclohexane uncertainty
EICOSA	Eicosane
EICOSAU	Eicosane uncertainty
DEC4YHX	Tetradecylcyclohexane
DEC4YHXU	Tetradecylcyclohexane uncertainty
HENEIC	Heneicosane
HENEICU	Heneicosane uncertainty
DEC5YHX	Pentadecylcyclohexane
DEC5YHXU	Pentadecylcyclohexane uncertainty
DOCOSA	Docosane
DOCOSAU	Docosane uncertainty
DEC6YHX	Hexadecylcyclohexane
DEC6YHXU	Hexadecylcyclohexane uncertainty
TRICOSA	Tricosane
TRICOSAU	Tricosane uncertainty
DEC7YHX	Heptadecylcyclohexane
DEC7YHXU	Heptadecylcyclohexane uncertainty
TETCOS	Tetracosane
TETCOSU	Tetracosane uncertainty
DEC8YHX	Octadecylcyclohexane
DEC8YHXU	Octadecylcyclohexane uncertainty

PENCOS	Pentacosane
PENCOSU	Pentacosane uncertainty
HEXCOS	Hexacosane
HEXCOSU	Hexacosane uncertainty
DEC9YHX	Nonadecylcyclohexane
DEC9YHXU	Nonadecylcyclohexane uncertainty
HEPCOS	Heptacosane
HEPCOSU	Heptacosane uncertainty
CYHXEIC	Eicosylcyclohexane
CYHXEICU	Eicosylcyclohexane uncertainty
OCTCOS	Octacosane
OCTCOSU	Octacosane uncertainty
NONCOS	Nonacosane
NONCOSU	Nonacosane uncertainty
CYHXHEN	Heneicosylcyclohexane
CYHXHENU	Heneicosylcyclohexane uncertainty
TRICONT	Triacontane
TRICONTU	Triacontane uncertainty
HTRICONT	Hentriacontane
HTRICONTU	Hentriacontane uncertainty
DTRICONT	Dotriacontane
DTRICONTU	Dotriacontane uncertainty
TTRICONT	Tritriacontane
TTRICONTU	Tritriacontane uncertainty
TETRICONT	Tetratriacontane
TETRICONTU	Tetratriacontane uncertainty
PTRICONT	Pentatriacontane
PTRICONTU	Pentatriacontane uncertainty
HXTRICONT	Hexatriacontane
HXTRICONTU	Hexatriacontane uncertainty
HPTRICONT	Heptatriacontane
HPTRICONTU	Heptatriacontane uncertainty
OTRICONT	Octatriacontane
OTRICONTU	Octatriacontane uncertainty
NTRICONT	Nonatriacontane
NTRICONTU	Nonatriacontane uncertainty
TECONT	Tetracontane
TECONTU	Tetracontane uncertainty

<u>Hopanes and Steranes</u>

HOP13	18α(H)-22,29,30-Trisnorhopane
HOP13U	18α(H)-22,29,30-Trisnorhopane uncertainty
HOP14	17α(H),18α(H),21β(H)-25,28,30-Trisnorhopane
HOP14U	17α(H),18α(H),21β(H)-25,28,30-Trisnorhopane uncertainty
HOP15	17α(H)-22,29,30-Trisnorhopane
HOP15U	17α(H)-22,29,30-Trisnorhopane uncertainty

HOP16	17α(H),18α(H),21ß(H)-28,30-Bisnorhopane
HOP16U	17α(H),18α(H),21ß(H)-28,30-Bisnorhopane uncertainty
HOP17	17α(H),21β(H)-29-Norhopane
HOP17U	17α(H),21β(H)-29-Norhopane uncertainty
HOP18	18α(H)- 29-Norneohopane
HOP18U	18α(H)- 29-Norneohopane uncertainty
HOP19	17α(H),21β(H)-Hopane
HOP19U	17α(H),21β(H)-Hopane uncertainty
HOP20	17β(H),21α(H)-Hopane
HOP20U	17 β(H),21α(H)-Hopane uncertainty
HOP21	22S-17α(H),21β(H)-30-Homohopane
HOP21U	22S-17α(H),21β(H)-30-Homohopane uncertainty
HOP22	22R-17α(H),21β(H)-30-Homohopane
HOP22U	22R-17α(H),21β(H)-30-Homohopane uncertainty
HOP23	17β(H),21 β(H)-Hopane
HOP23U	17β(H)),21 β(H)-Hopane uncertainty
HOP24	22S-17α(H),21β(H)-30,31-Bishomohopane
HOP24U	22S-17α(H),21β(H)-30,31-Bishomohopane uncertainty
HOP25	22R-17α(H),21β(H)-30,31-Bishomohopane
HOP25U	22R-17α(H),21β(H)-30,31-Bishomohopane uncertainty
HOP26	22S-17α(H),21β(H)-30,31,32-Trisomohopane
HOP26U	22S-17α(H),21β(H)-30,31,32-Trisomohopane uncertainty
HOP27	22R-17α(H),21β(H)-30,31,32-Trishomohopane
HOP27U	22R-17α(H),21β(H)-30,31,32-Trishomohopane uncertainty
STER35	20S-13ß(H),17α(H)-Diacholestane
STER35U	20S-13ß(H),17α(H)-Diacholestane uncertainty
STER36	20R-13ß(H),17α(H)-Diacholestane
STER36U	20R-13ß(H),17α(H)-Diacholestane uncertainty
STER37	20S-13α(H),17ß(H)-Diacholestane
STER37U	20S-13α(H),17ß(H)-Diacholestane uncertainty
STER38	20R-13α(H),17ß(H)-Diacholestane
STER38U	20R-13α(H),17ß(H)-Diacholestane uncertainty
STER39	20S-13ß(H),17α(H)-Diaergostane
STER39U	20S-13ß(H),17α(H)-Diaergostane uncertainty
STER42	20S5α(H),14α(H)-Cholestane
STER42U	20S5α(H),14α(H)-Cholestane uncertainty
STER43	20R5α(H),14β(H)-Cholestane
STER43U	20R5α(H),14β(H)-Cholestane uncertainty
STER44	20S5α(H),14β(H),17β(H)-Cholestane
STER44U	20S5α(H),14β(H),17β(H)-Cholestane uncertainty
STER45_40	20R-5α(H),14α(H),17α(H)-Cholestane & 20S-13ß(H),17α(H)-diastigmastane
STER45_40U	20R-5α(H),14α(H),17α(H)-Cholestane & 20S-13ß(H),17α(H)-diastigmastane uncertainty
STER46	20S5α(H),14α(H),17α(H)-Ergostane
STER46U	20S5α(H),14α(H),17α(H)-Ergostane uncertainty
STER47	20R5α(H),14β(H),17β(H)-Ergostane
STER47U	20R5α(H),14β(H),17β(H)-Ergostane uncertainty

STER48_41	20S-5α(H),14ß(H),17ß(H)-Ergostane&20R-13α(H),17ß(H) diastigmastane
STER48_41U	20S-5α(H),14ß(H),17ß(H)-Ergostane & 20R-13α(H),17ß(H)-diastigmastane uncertainty
STER49	20R5α(H),14α(H),17α(H)-Ergostane
STER49U	20R5α(H),14α(H),17α(H)-Ergostane uncertainty
STER50	20S5α(H),14α(H),17α(H)-Stigmastane
STER50U	20S5α(H),14α(H),17α(H)-Stigmastane uncertainty
STER51	20R5α(H),14β(H),17β(H)-Stigmastane
STER51U	20R5α(H),14β(H),17β(H)-Stigmastane uncertainty
STER52	20S5α(H),14β(H),17β(H)-Stigmastane
STER52U	20S5α(H),14β(H),17β(H)-Stigmastane uncertainty
STER53	20R5α(H),14α(H),17α(H)-Stigmastane
STER53U	20R5α(H),14α(H),17α(H)-Stigmastane uncertainty

Nitrosamines

NDMA	N-nitrosodi-N-methylamine
NDMAU	N-nitrosodi-N-methylamine uncertainty
NDEA	N-nitrosodi-N-ethylamine
NDEAU	N-nitrosodi-N-ethylamine uncertainty
NDPA	N-nitrosodi-N-propylamine
NDPAU	N-nitrosodi-N-propylamine uncertainty
NNMUR	N-nitroso-N-methylurea
NNMURU	N-nitroso-N-methylurea uncertainty
NDBA	N-nitrosodi-N-butylamine
NDBAU	N-nitrosodi-N-butylamine uncertainty
NPPD	N-nitrosopiperidine
NPPDU	N-nitrosopiperidine uncertainty
NPYR	N-nitrosopyrrolidine
NPYRU	N-nitrosopyrrolidine uncertainty
NMRP	N-nitrosomorpholine
NMRPU	N-nitrosomorpholine uncertainty

Metals and Elements

NAXC	Sodium concentration (µg/filter) (qualitative only)
NAXU	Sodium concentration (µg/filter) uncertainty
MGXC	Magnesium concentration (µg/filter) (qualitative only)
MGXU	Magnesium concentration (µg/filter) uncertainty
ALXC	Aluminum concentration (µg/filter)
ALXU	Aluminum concentration (µg/filter) uncertainty
SIXC	Silicon concentration (µg/filter)
SIXU	Silicon concentration (µg/filter) uncertainty
PHXC	Phosphorous concentration (µg/filter)
PHXU	Phosphorous concentration (µg/filter) uncertainty
SUXC	Sulfur concentration (µg/filter)
SUXU	Sulfur concentration (µg/filter) uncertainty

CLXC	Chlorine concentration (µg/filter)
CLXU	Chlorine concentration (µg/filter) uncertainty
KPXC	Potassium concentration (µg/filter)
KPXU	Potassium concentration (µg/filter) uncertainty
CAXC	Calcium concentration (µg/filter)
CAXU	Calcium concentration (µg/filter) uncertainty
SCXC	Scandium concentration (µg/filter)
SCXU	Scandium concentration (µg/filter) uncertainty
TIXC	Titanium concentration (µg/filter)
TIXU	Titanium concentration (µg/filter) uncertainty
VAXC	Vanadium concentration (µg/filter)
VAXU	Vanadium concentration (µg/filter) uncertainty
CRXC	Chromium concentration (µg/filter)
CRXU	Chromium concentration (µg/filter) uncertainty
MNXC	Manganese concentration (µg/filter)
MNXU	Manganese concentration (µg/filter) uncertainty
FEXC	Iron concentration (µg/filter)
FEXU	Iron concentration (µg/filter) uncertainty
COXC	Cobalt concentration (µg/filter)
COXU	Cobalt concentration (µg/filter) uncertainty
NIXC	Nickel concentration (µg/filter)
NIXU	Nickel concentration (µg/filter) uncertainty
CUXC	Copper concentration (µg/filter)
CUXU	Copper concentration (µg/filter) uncertainty
ZNXC	Zinc concentration (µg/filter)
ZNXU	Zinc concentration (µg/filter) uncertainty
GAXC	Gallium concentration (µg/filter)
GAXU	Gallium concentration (µg/filter) uncertainty
ASXC	Arsenic concentration (µg/filter)
ASXU	Arsenic concentration (µg/filter) uncertainty
SEXC	Selenium concentration (µg/filter)
SEXU	Selenium concentration (µg/filter) uncertainty
BRXC	Bromine concentration (µg/filter)
BRXU	Bromine concentration (µg/filter) uncertainty
RBXC	Rubidium concentration (µg/filter)
RBXU	Rubidium concentration (µg/filter) uncertainty
SRXC	Strontium concentration (µg/filter)
SRXU	Strontium concentration (µg/filter) uncertainty
YTXC	Yttrium concentration (µg/filter)
YTXU	Yttrium concentration (µg/filter) uncertainty
ZRXC	Zirconium concentration (µg/filter)
ZRXU	Zirconium concentration (µg/filter) uncertainty
NBXC	Niobium concentration (µg/filter)
NBXU	Niobium concentration (µg/filter) uncertainty
MOXC	Molybdenum concentration (µg/filter)
MOXU	Molybdenum concentration (µg/filter) uncertainty
PDXC	Palladium concentration (µg/filter)
PDXU	Palladium concentration (µg/filter) uncertainty

AGXC	Silver concentration (µg/filter)
AGXU	Silver concentration (µg/filter) uncertainty
CDXC	Cadmium concentration (µg/filter)
CDXU	Cadmium concentration (µg/filter) uncertainty
INXC	Indium concentration (µg/filter)
INXU	Indium concentration (µg/filter) uncertainty
SNXC	Tin concentration (µg/filter)
SNXU	Tin concentration (µg/filter) uncertainty
SBXC	Antimony concentration (µg/filter)
SBXU	Antimony concentration (µg/filter) uncertainty
CSXC	Cesium concentration (µg/filter)
CSXU	Cesium concentration (µg/filter) uncertainty
BAXC	Barium concentration (µg/filter)
BAXU	Barium concentration (µg/filter) uncertainty
LAXC	Lanthanum concentration (µg/filter)
LAXU	Lanthanum concentration (µg/filter) uncertainty
CEXC	Cerium concentration (µg/filter)
CEXU	Cerium concentration (µg/filter) uncertainty
SMXC	Samarium concentration (µg/filter)
SMXU	Samarium concentration (µg/filter) uncertainty
EUXC	Europium concentration (µg/filter)
EUXU	Europium concentration (µg/filter) uncertainty
TBXC	Terbium concentration (µg/filter)
TBXU	Terbium concentration (µg/filter) uncertainty
HFXC	Hafnium concentration (µg/filter)
HFXU	Hafnium concentration (µg/filter) uncertainty
TAXC	Tantalum concentration (µg/filter)
TAXU	Tantalum concentration (µg/filter) uncertainty
WOXC	Tungsten concentration (µg/filter)
WOXU	Tungsten concentration (µg/filter) uncertainty
IRXC	Iridium concentration (µg/filter)
IRXU	Iridium concentration (µg/filter) uncertainty
AUXC	Gold concentration (µg/filter)
AUXU	Gold concentration (µg/filter) uncertainty
HGXC	Mercury concentration (µg/filter)
HGXU	Mercury concentration (µg/filter) uncertainty
TLXC	Thallium concentration (µg/filter)
TLXU	Thallium concentration (µg/filter) uncertainty
PBXC	Lead concentration (µg/filter)
PBXU	Lead concentration (µg/filter) uncertainty
URXC	Uranium concentration (µg/filter)
URXU	Uranium concentration (µg/filter) uncertainty

APPENDIX C

PAH, HOPANES, AND STERANES MASS CONCENTRATION IN FUEL AND LUBE OIL

TABLE C-1. FUEL AND LUBE OIL PAH

	Fresh Oil	Engine A	Engine B	Engine C	Engine D	Fuel
	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g
naphth	0.00	0.13	1.66	0.00	12.14	291.86
naphthu	0.04	0.04	0.09	0.04	0.65	15.84
quinoline	0.00	0.00	0.00	0.00	0.00	41.08
quinolineu	0.04	0.04	0.04	0.04	0.04	5.26
mnaph2	0.00	0.35	0.00	0.16	20.06	1695.80
mnaph2u	0.04	0.04	0.04	0.04	0.96	80.81
mnaph1	0.00	0.17	0.12	0.04	7.96	1000.20
mnaph1u	0.04	0.04	0.04	0.04	0.42	52.76
biphen	0.00	0.56	0.12	0.00	0.69	548.93
biphenu	0.04	0.05	0.04	0.04	0.04	24.76
enap12	0.00	0.61	0.04	0.08	2.54	473.80
enap12u	0.04	0.09	0.04	0.04	0.34	64.94
m_2bph	0.00	0.22	0.00	0.00	0.36	13.94
m_2bphu	0.04	0.04	0.04	0.04	0.04	0.56
dmn267	0.00	5.13	0.04	0.78	7.30	3403.16
dmn267u	0.04	0.28	0.04	0.05	0.41	184.80
dm1367	0.00	6.47	0.39	1.60	14.32	6299.48
dm1367u	0.04	0.34	0.04	0.09	0.75	334.84
d14523	0.00	0.91	0.04	0.47	3.45	2196.19
d14523u	0.04	0.05	0.04	0.04	0.22	127.01
acnapy	0.00	0.00	3.55	0.00	0.07	1.37
acnapyu	0.04	0.04	0.74	0.04	0.04	0.28
dmn12	0.00	0.04	0.00	0.16	1.05	439.35
dmn12u	0.04	0.04	0.04	0.04	0.11	51.75
dmn18	0.00	0.00	0.00	0.00	0.00	0.90
dmn18u	0.04	0.04	0.04	0.04	0.04	0.16
acnape	0.19	0.04	0.04	0.12	0.04	10.31
acnapeu	0.04	0.04	0.04	0.04	0.04	1.64
m_3bph	0.00	7.78	0.15	0.35	5.71	1044.48
m_3bphu	0.04	0.26	0.04	0.04	0.19	35.37
m_4bph	0.00	0.17	0.00	0.00	1.16	462.90
m_4bphu	0.04	0.04	0.04	0.04	0.05	20.95
dbzfur	0.00	0.13	0.00	0.00	0.11	46.08
dbzfuru	0.04	0.04	0.04	0.04	0.04	1.64
bibenz	0.00	0.09	0.00	0.00	0.73	131.01
bibenzu	0.04	0.04	0.04	0.04	0.11	16.22
em_12n	0.00	0.48	0.04	0.04	0.69	195.29
em_12nu	0.04	0.09	0.04	0.04	0.15	37.40
tmi235n	0.00	1.00	0.15	0.39	2.36	657.96
tmi235nu	0.04	0.05	0.04	0.04	0.13	34.89
btmnap	0.00	5.47	0.08	1.91	10.90	1293.11
btmnapu	0.04	0.51	0.04	0.17	1.05	122.41
atmnap	0.00	4.30	0.12	1.01	5.34	1373.16
atmnapu	0.04	0.23	0.04	0.08	0.28	74.99

TABLE C-1 (CONT'D.) FUEL AND LUBE OIL PAH

	Fresh Oil	Engine A	Engine B	Engine C	Engine D	Fuel
	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g
ctmnap	0.00	5.39	0.08	2.30	10.32	1162.57
ctmnapu	0.04	0.25	0.04	0.11	0.45	51.13
em_21n	0.04	0.13	0.12	0.00	0.15	26.01
em_21nu	0.04	0.04	0.04	0.04	0.04	3.77
etmnap	0.00	2.56	0.12	0.70	7.49	817.75
etmnapu	0.04	0.12	0.04	0.05	0.33	35.49
tm245n	0.00	0.17	0.12	0.16	0.22	150.42
tm245nu	0.04	0.04	0.04	0.04	0.04	8.83
ftmnap	0.00	3.48	0.15	0.86	2.40	678.42
ftmnapu	0.04	0.17	0.04	0.05	0.14	33.85
fluore	0.00	0.78	0.46	0.12	0.87	79.43
fluoreu	0.04	0.18	0.12	0.04	0.18	15.50
tm145n	0.00	0.87	0.00	0.31	1.45	34.52
tm145nu	0.04	0.13	0.04	0.08	0.22	5.51
jtmnap	0.23	1.30	0.19	0.43	2.83	311.04
jtmnapu	0.04	0.14	0.04	0.04	0.27	29.42
a_mfluo	0.19	0.43	0.00	0.16	0.47	255.62
a_mfluou	0.04	0.05	0.04	0.04	0.04	22.92
b_mfluo	0.00	0.17	0.00	0.04	0.25	93.41
b_mfluou	0.04	0.04	0.04	0.04	0.04	11.26
m_1fluo	0.15	1.00	0.00	0.58	1.24	146.99
m_1fluou	0.04	0.13	0.04	0.08	0.19	21.65
fl9one	0.00	0.22	0.08	0.16	0.51	12.54
fl9oneu	0.04	0.04	0.04	0.04	0.04	1.03
dbth	0.00	0.00	0.00	0.04	0.07	8.63
dbthu	0.04	0.04	0.04	0.04	0.04	1.36
phenan	0.00	1.82	14.85	0.43	3.67	144.80
phenanu	0.04	0.11	0.79	0.04	0.19	7.71
anthra	0.00	0.17	0.08	0.16	0.76	22.77
anthrau	0.04	0.04	0.04	0.04	0.18	4.90
xanone	0.00	1.91	0.15	0.19	8.10	558.11
xanoneu	0.04	0.83	0.08	0.08	3.50	240.76
acquone	0.00	0.00	0.58	0.62	12.17	968.80
acquoneu	0.04	0.04	0.04	0.04	0.74	58.20
m_2phen	0.00	1.74	0.50	1.01	8.69	222.59
m_2phenu	0.04	0.31	0.08	0.16	1.45	36.68
m_3phen	0.27	1.09	0.50	1.36	8.07	216.53
m_3phenu	0.08	0.22	0.12	0.24	1.48	40.10
pnapone	0.00	0.39	0.54	0.78	1.05	22.18
pnaponeu	0.04	0.09	0.08	0.12	0.15	2.94
m_2anth	0.08	0.09	0.00	0.12	0.18	2.15
m_2anthu	0.04	0.04	0.04	0.04	0.04	0.47
m_45phen	0.00	0.43	4.63	0.23	1.05	1.17
m_45phenu	0.04	0.09	1.05	0.08	0.22	0.28

TABLE C-1 (CONT'D.) FUEL AND LUBE OIL PAH

	Fresh Oil	Engine A	Engine B	Engine C	Engine D	Fuel
	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g
m_9phen	0.38	0.52	0.58	1.09	2.98	82.44
m_9phenu	0.08	0.09	0.12	0.20	0.55	15.63
mpht_1	0.00	0.39	0.66	0.62	3.71	82.44
mpht_1u	0.04	0.05	0.08	0.08	0.45	9.95
dbpht	4.66	3.13	2.58	6.38	2.62	1.33
dbphtu	0.55	0.36	0.32	0.77	0.30	0.16
anthron	0.57	0.74	0.35	1.13	0.51	12.22
anthronu	0.15	0.18	0.08	0.27	0.11	2.88
m_9ant	0.00	0.13	0.12	0.35	0.18	4.02
m_9antu	0.04	0.04	0.04	0.08	0.04	0.56
nap2phen	0.30	0.22	1.23	0.12	0.22	0.31
nap2phenu	0.04	0.04	0.16	0.04	0.04	0.04
anrquone	0.27	0.70	0.15	0.47	0.29	4.06
anrquoneu	0.08	0.13	0.04	0.12	0.07	0.83
a_dmph	0.42	1.04	0.19	1.13	6.80	169.09
a_dmphu	0.08	0.13	0.04	0.16	0.90	22.13
b_dmph	0.00	1.22	0.31	0.82	3.89	86.54
b_dmphu	0.04	0.22	0.08	0.16	0.67	15.19
dm17ph	1.29	0.83	0.89	0.47	5.63	114.22
dm17phu	0.16	0.09	0.12	0.08	0.65	12.84
dm36ph	0.27	0.26	0.12	0.16	2.76	120.55
dm36phu	0.04	0.04	0.04	0.04	0.41	17.46
d_dmph	0.49	1.09	0.12	0.47	4.11	64.86
d_dmphu	0.15	0.31	0.04	0.16	1.17	18.52
e_dmph	0.42	0.39	0.15	0.43	3.53	71.97
e_dmphu	0.08	0.09	0.04	0.08	0.63	13.03
c_dmph	2.65	2.74	2.08	3.23	9.41	230.40
c_dmphu	0.46	0.44	0.35	0.56	1.59	38.69
fluora	0.00	0.43	24.65	0.93	0.29	0.74
fluorau	0.04	0.09	5.39	0.20	0.07	0.16
pyrene	1.02	1.91	46.17	1.17	4.18	142.89
pyreneu	0.16	0.31	7.26	0.20	0.67	22.50
antal9	0.72	0.96	0.89	3.42	2.22	30.34
antal9u	0.12	0.18	0.16	0.56	0.37	5.02
retene	0.08	0.09	0.12	0.31	0.15	0.62
reteneu	0.04	0.04	0.04	0.04	0.04	0.04
bafluo	1.70	2.78	0.93	0.93	1.89	2.19
bafluou	0.46	0.74	0.23	0.24	0.51	0.59
bbfluo	0.19	0.52	0.62	1.63	0.33	0.20
bbfluou	0.08	0.13	0.16	0.43	0.11	0.08
bmpyfl	0.83	0.35	0.58	1.25	1.42	0.94
bmpyflu	0.15	0.09	0.12	0.24	0.26	0.16
c1mflpy	0.98	0.83	2.24	0.74	1.56	2.93
c1mflpyu	0.15	0.13	0.39	0.12	0.26	0.52

TABLE C-1 (CONT'D.) FUEL AND LUBE OIL PAH

	Fresh Oil	Engine A	Engine B	Engine C	Engine D	Fuel
	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g
m_13fl	0.57	0.61	0.62	1.28	1.02	1.37
m_13flu	0.15	0.17	0.19	0.39	0.29	0.39
m_4pyr	0.68	1.65	1.12	1.36	5.42	88.92
m_4pyru	0.04	0.10	0.09	0.09	0.28	4.57
cmpyfl	0.34	1.09	1.20	3.23	0.65	0.35
cmpyflu	0.11	0.31	0.35	0.94	0.18	0.12
dmpyfl	1.33	1.09	1.35	0.74	7.01	98.68
dmpyflu	0.19	0.18	0.20	0.12	1.04	14.48
m_1pyr	0.98	1.17	2.70	1.13	1.85	66.27
m_1pyru	0.19	0.22	0.51	0.24	0.37	12.84
bntiop	1.17	0.74	1.74	0.97	1.02	0.16
bntiopu	0.23	0.18	0.35	0.20	0.22	0.04
bzcphen	0.61	0.78	1.27	0.54	1.53	0.16
bzcphenu	0.23	0.31	0.46	0.20	0.55	0.08
bghifl	1.33	1.39	0.85	0.51	0.25	2.93
bghiflu	0.16	0.18	0.12	0.08	0.04	0.36
phant9	0.45	0.26	0.12	0.12	0.22	0.00
phant9u	0.11	0.09	0.04	0.04	0.07	0.04
cp_cdpyr	0.45	0.48	0.58	0.16	0.55	0.16
cp_cdpyru	0.08	0.09	0.12	0.04	0.11	0.04
baanth	0.00	0.39	3.90	0.27	0.29	0.23
baanthu	0.04	0.09	0.86	0.08	0.07	0.08
chr_tr	2.31	0.83	7.56	1.13	1.05	1.41
chr_tru	0.31	0.13	1.00	0.16	0.15	0.20
bzanthr	0.91	2.13	2.24	1.79	3.42	0.51
bzanthru	0.19	0.48	0.51	0.39	0.77	0.12
b2epht	3.94	5.17	1.23	4.05	7.78	2.42
b2ephtu	0.40	0.51	0.12	0.41	0.77	0.25
baa7_12	0.00	1.69	7.29	2.18	4.54	0.35
baa7_12u	0.04	0.44	1.79	0.55	1.10	0.08
m_3chr	0.19	0.22	0.31	0.23	0.33	0.27
m_3chru	0.04	0.04	0.04	0.04	0.07	0.04
chry56m	0.27	0.35	0.27	0.51	0.80	0.08
chry56mu	0.04	0.04	0.04	0.04	0.05	0.04
m_7baa	0.68	0.39	0.35	0.90	1.05	0.16
m_7baau	0.12	0.09	0.08	0.16	0.19	0.04
dmban712	0.34	1.35	0.35	0.51	0.80	0.39
dmban712u	0.04	0.14	0.04	0.04	0.08	0.04
bbjkfl	0.27	0.43	0.85	0.58	2.07	0.12
bbjkflu	0.04	0.05	0.12	0.08	0.23	0.04
bafl	0.00	0.13	0.08	0.08	0.15	0.00
baflu	0.04	0.04	0.04	0.04	0.04	0.04
bepyrn	0.30	0.35	8.14	0.51	0.33	0.62
bepyrnu	0.11	0.13	2.71	0.16	0.11	0.20

TABLE C-1 (CONT'D.) FUEL AND LUBE OIL PAH

	Fresh Oil	Engine A	Engine B	Engine C	Engine D	Fuel
	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g
bapyrn	0.57	0.39	8.52	0.08	0.18	0.08
bapyrnu	0.04	0.05	0.68	0.04	0.04	0.04
peryle	0.11	0.17	2.43	0.31	0.40	0.08
peryleu	0.04	0.04	0.14	0.04	0.04	0.04
mchol3	0.00	0.52	0.23	0.54	0.29	0.12
mchol3u	0.04	0.09	0.08	0.12	0.07	0.04
m_7bpy	0.15	0.09	0.19	0.43	0.11	0.08
m_7bpyu	0.04	0.04	0.04	0.08	0.04	0.04
bpy910dih	0.23	0.30	0.54	0.19	0.62	0.00
bpy910dihu	0.08	0.09	0.12	0.04	0.15	0.04
incdfl	0.68	0.52	0.58	0.31	0.47	0.00
incdflu	0.04	0.05	0.04	0.04	0.04	0.04
dbahacr	0.38	1.00	0.27	0.39	0.62	0.00
dbahacru	0.04	0.09	0.04	0.04	0.04	0.04
dbajacr	0.19	1.04	0.42	0.31	0.36	0.00
dbajacru	0.08	0.26	0.12	0.08	0.11	0.04
in123pyr	0.30	1.35	0.69	0.39	0.44	0.00
in123pyru	0.04	0.06	0.04	0.04	0.04	0.04
dbajan	0.42	1.43	0.46	0.31	0.98	0.00
dbajanu	0.08	0.31	0.12	0.08	0.18	0.04
dbahacan	0.00	2.09	0.58	0.78	1.27	0.00
dbahacanu	0.04	0.08	0.04	0.05	0.06	0.04
bbchr	0.00	0.96	0.08	0.58	0.62	0.00
bbchru	0.04	0.05	0.04	0.04	0.04	0.04
pic	0.87	0.70	0.46	0.54	0.65	0.00
picu	0.23	0.22	0.12	0.16	0.18	0.04
dbcgcar	1.82	1.00	1.74	0.90	0.98	1.37
dbcgcaru	0.46	0.26	0.43	0.24	0.26	0.35
bghipe	0.64	0.39	28.08	0.93	0.44	0.04
bghipeu	0.12	0.09	5.44	0.20	0.07	0.04
anthan	0.00	0.39	0.58	0.35	0.25	0.00
anthanu	0.04	0.05	0.04	0.04	0.04	0.04
dbalpyr	0.19	0.22	0.69	0.47	0.29	0.00
dbalpyru	0.04	0.04	0.04	0.04	0.04	0.04
dbaepyr	0.19	0.13	0.19	0.00	0.18	0.04
dbaepyru	0.08	0.04	0.08	0.04	0.07	0.04
corone	0.00	0.13	7.56	0.23	0.15	0.04
coroneu	0.04	0.04	1.91	0.08	0.04	0.04
dbaipyr	0.27	0.04	0.19	0.00	0.18	0.00
dbaipyru	0.04	0.04	0.04	0.04	0.04	0.04
dbahpyr	0.00	0.22	0.31	0.00	0.15	0.00
dbahpyru	0.04	0.04	0.04	0.04	0.04	0.04
dbbkfl	0.23	0.13	0.81	0.43	0.22	0.00
dbbkflu	0.04	0.04	0.05	0.04	0.04	0.04
Sum PAH	**42.72**	**115.35**	**215.07**	**76.31**	**279.66**	**29049.4**
u is designated for measurement uncertainty or limit of detection						

TABLE C-2. OIL AND FUEL HOPANES AND STERANES

	Fresh Oil	Engine A	Engine B	Engine C	Engine D	Fuel
	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g
hop13	20.59	23.71	38.10	51.36	173.45	0.00
hop13u	2.44	2.81	4.52	6.10	20.59	0.00
hop14	2.15	2.44	5.00	3.68	87.94	0.00
hop14u	0.09	0.10	0.21	0.15	3.65	0.00
hop15	28.81	24.75	33.88	20.02	116.96	0.04
hop15u	1.72	1.48	2.02	1.20	10.17	0.00
hop16	5.91	4.21	5.63	5.29	6.96	0.00
hop16u	0.38	0.27	0.36	0.34	0.45	0.00
hop17	51.92	48.69	170.39	89.73	404.51	0.06
hop17u	2.18	2.05	7.16	3.77	17.00	0.00
hop18	4.80	2.01	1.63	4.84	0.00	0.00
hop18u	0.24	0.10	0.08	0.24	0.00	0.00
hop19	17.79	19.38	120.42	40.54	134.20	0.00
hop19u	1.11	1.21	7.51	2.53	8.37	0.00
hop20	2.91	1.26	8.13	3.26	20.29	0.00
hop20u	0.38	0.16	1.06	0.42	2.65	0.00
hop21	12.19	12.61	131.39	21.26	44.87	0.00
hop21u	0.77	0.79	8.26	1.34	2.82	0.00
hop22	8.21	13.05	128.54	21.16	61.06	0.00
hop22u	0.55	0.87	8.61	1.42	4.09	0.00
hop23	0.00	0.00	2.78	2.08	1.33	0.00
hop23u	0.00	0.00	0.14	0.10	0.07	0.00
hop24	5.86	10.43	111.78	12.90	33.16	0.00
hop24u	0.70	1.25	13.42	1.55	3.98	0.00
hop25	3.98	6.28	84.95	8.58	15.81	0.00
hop25u	0.47	0.74	9.99	1.01	1.86	0.00
hop26	2.79	5.23	108.96	10.25	16.86	0.00
hop26u	0.51	0.96	19.95	1.88	3.09	0.00
hop27	1.76	3.56	70.32	7.32	7.51	0.00
hop27u	0.09	0.17	3.40	0.35	0.36	0.00
sum hopanes	**169.66**	**177.61**	**1021.89**	**302.27**	**1124.91**	**0.1**
u is designated for measurement uncertainty or limit of detection						

TABLE C-2 (CONT'D.) OIL AND FUEL HOPANES AND STERANES

	Fresh Oil	Engine A	Engine B	Engine C	Engine D	Fuel
	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g
ster35	12.70	7.39	11.22	17.99	3.24	0.00
ster35u	0.36	0.21	0.32	0.52	0.09	0.00
ster36	6.91	3.94	9.70	12.13	6.52	0.00
ster36u	0.69	0.39	0.97	1.21	0.65	0.00
ster37	1.81	2.46	3.71	2.70	39.11	0.00
ster37u	0.13	0.17	0.26	0.19	2.75	0.00
ster38	4.30	2.48	3.51	5.67	32.59	0.00
ster38u	0.58	0.33	0.47	0.76	4.39	0.00
ster39	5.27	4.00	5.78	8.46	66.23	0.00
ster39u	0.51	0.38	0.56	0.81	6.36	0.00
ster42	10.86	9.53	10.29	10.33	25.28	0.00
ster42u	1.14	1.00	1.08	1.08	2.65	0.00
ster43	21.63	12.49	10.47	30.23	51.89	0.00
ster43u	0.91	0.53	0.44	1.27	2.18	0.00
ster44	12.63	7.38	21.04	18.11	39.79	0.00
ster44u	1.44	0.84	2.39	2.06	4.53	0.00
ster45_40	18.90	8.39	27.24	22.60	27.22	0.00
ster45_40u	0.55	0.24	0.79	0.66	0.79	0.00
ster46	5.34	8.65	5.09	7.53	55.87	0.00
ster46u	0.35	0.57	0.33	0.49	3.66	0.00
ster47	4.42	6.32	11.41	11.45	42.08	0.00
ster47u	0.38	0.54	0.98	0.98	3.61	0.00
ster48_41	10.90	8.62	11.97	29.67	16.90	0.00
ster48_41u	1.09	0.87	1.20	2.98	1.70	0.00
ster49	4.51	0.18	9.49	7.07	58.03	0.00
ster49u	1.23	0.05	2.60	1.93	15.87	0.00
ster50	4.27	4.32	7.39	5.80	22.13	0.00
ster50u	0.37	0.37	0.64	0.50	1.92	0.00
ster51	10.64	8.55	27.93	19.63	64.91	0.00
ster51u	1.68	1.35	4.40	3.09	10.22	0.00
ster52	7.93	5.73	22.87	13.40	88.23	0.00
ster52u	1.04	0.75	3.01	1.76	11.60	0.00
ster53	3.75	9.02	17.00	12.11	4.99	0.00
ster53u	0.50	1.21	2.28	1.62	0.67	0.00
sum steranes	**146.77**	**109.45**	**216.13**	**234.89**	**645.02**	**0**
u is designated for measurement uncertainty or limit of detection						

APPENDIX D

METALS AND ELEMENTS EMISSIONS IN µG/HP-HR

TABLE D-1. ENGINE A METALS AND ELEMENTS

	FTP-w-1	FTP-w-2	FTP-w-3	FTP-wo-1	FTP-wo-2	FTP-wo-3	CARBx-1	CARBx-2	CARBz-1	CARBz-1	16-Hour-1	16-Hour-2	16-Hour-3	TB-1	TB-2	TB-3	TB-4
	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr
NAXC	0.00	0.00	128.82	88.89	53.67	42.58	0.00	0.00	75.29	32.57	32.70	22.99	28.29	0.00	0.00	457.06	0.00
NAXU	509.87	509.87	528.00	437.25	386.22	386.60	1481.69	1498.13	146.39	123.70	7.71	6.19	6.18	1623.90	450.86	469.12	456.30
MGXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.82	2.39	0.76	811.76	0.00	0.00	0.00
MGXU	273.91	272.67	280.23	231.18	204.20	204.98	789.05	796.40	76.93	65.32	3.77	3.07	2.99	341.67	244.97	245.27	244.18
ALXC	28.53	0.00	0.00	20.79	0.00	21.40	0.00	176.77	13.23	7.03	2.34	1.64	3.24	0.00	0.00	0.00	18.43
ALXU	45.25	44.91	46.24	38.32	33.68	33.94	130.79	133.12	12.84	10.83	0.63	0.51	0.51	576.38	40.22	40.22	40.47
SIXC	44.08	0.00	0.00	0.00	0.00	58.04	0.00	51.99	0.00	3.83	2.40	0.45	2.16	0.00	0.00	0.00	0.00
SIXU	50.73	50.34	51.51	42.68	37.75	38.26	145.68	148.17	14.20	12.14	0.70	0.56	0.56	3206.69	45.08	45.08	45.08
PHXC	0.00	9.45	8.76	1.31	0.00	0.00	13.40	34.07	37.38	73.08	18.45	15.27	14.34	55.30	1.38	21.41	80.23
PHXU	14.43	14.74	15.08	12.22	10.80	10.82	41.70	43.10	4.24	3.75	0.27	0.23	0.22	13.03	12.90	13.20	13.20
SUXC	0.00	106.86	0.00	77.99	88.65	71.68	242.08	386.78	846.94	1710.74	383.70	302.24	280.54	0.00	52.54	51.37	1844.69
SUXU	40.29	40.56	41.17	34.39	30.62	30.46	117.38	119.44	15.35	18.50	2.74	2.17	2.03	36.03	36.32	36.32	44.45
CLXC	0.00	1.78	0.00	5.24	3.65	5.27	2.57	130.66	0.00	0.01	0.19	0.23	0.17	0.00	8.67	0.00	0.00
CLXU	9.93	9.92	10.15	8.41	7.44	7.45	28.70	29.00	2.80	2.38	0.14	0.11	0.11	10.56	8.88	8.88	8.88
KPXC	10.96	2.62	4.45	0.00	4.24	2.95	0.00	158.71	0.12	1.67	0.82	0.36	0.61	213.76	1.17	0.00	5.49
KPXU	9.28	9.26	9.48	7.85	6.95	6.96	26.81	27.09	2.61	2.22	0.13	0.10	0.10	360.48	8.30	8.30	8.30
CAXC	34.01	12.49	17.28	0.00	0.84	7.10	79.20	188.94	10.94	14.11	13.81	11.29	12.73	1894.51	2.93	2.56	91.96
CAXU	11.15	11.13	11.39	9.44	8.35	8.36	32.22	32.56	3.14	2.67	0.17	0.14	0.14	356.63	9.97	9.97	10.26
SCXC	1.97	0.00	6.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.14	0.06	7.46	0.00	0.00	0.00
SCXU	36.59	36.54	37.39	30.98	27.40	27.44	105.74	106.85	10.31	8.75	0.50	0.41	0.40	33.85	32.72	32.72	32.72
TIXC	2.62	8.28	0.00	0.00	3.61	0.32	0.00	12.72	0.00	0.00	0.07	0.06	0.33	68.21	0.00	0.38	1.17
TIXU	6.84	6.83	6.99	5.79	5.12	5.13	19.77	19.98	1.93	1.64	0.09	0.08	0.07	41.06	6.12	6.12	6.12
VAXC	2.20	0.00	0.00	1.47	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.01	0.00	3.14	0.00	0.38
VAXU	0.61	0.61	0.62	0.52	0.46	0.46	1.76	1.78	0.17	0.15	0.01	0.01	0.01	4.44	0.54	0.54	0.54
CRXC	0.66	0.00	5.60	0.00	0.00	0.00	0.00	8.35	1.29	1.00	0.37	0.24	1.28	0.00	0.00	0.59	31.97
CRXU	6.23	6.22	6.37	5.28	4.67	4.67	18.01	18.20	1.76	1.49	0.09	0.07	0.07	5.57	5.57	5.57	5.57
MNXC	0.47	5.71	0.00	5.59	0.00	0.00	29.24	0.00	2.48	1.37	0.19	0.11	0.23	78.05	0.00	0.00	0.00
MNXU	13.07	13.05	13.36	11.07	9.79	9.80	37.77	38.17	3.68	3.13	0.18	0.15	0.14	14.12	11.69	11.69	11.69
FEXC	17.52	37.24	19.29	13.37	12.49	13.14	87.46	240.80	16.92	13.01	12.07	9.46	15.42	289.80	0.00	2.35	203.91
FEXU	16.77	16.75	17.14	14.20	12.56	12.58	48.47	49.80	4.80	4.08	0.25	0.20	0.21	56.56	15.00	15.00	15.25
COXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COXU	0.61	0.61	0.62	0.52	0.46	0.46	1.76	1.78	0.17	0.15	0.01	0.01	0.01	0.54	0.54	0.54	0.54
NIXC	0.00	2.01	0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.00	0.00	0.01	0.41	17.26	0.00	2.97	13.16
NIXU	3.09	3.09	3.16	2.62	2.32	2.32	8.94	9.03	0.87	0.74	0.04	0.03	0.03	2.77	2.77	2.77	2.77
CUXC	0.00	1.96	5.60	0.00	1.16	0.00	0.00	17.38	1.80	1.42	0.15	0.16	0.53	816.87	0.21	4.90	25.68
CUXU	5.57	5.57	5.70	4.72	4.17	4.18	16.11	16.28	1.57	1.33	0.08	0.06	0.06	7.29	4.99	4.99	4.99
ZNXC	28.29	16.42	6.94	0.00	2.81	20.91	22.20	72.38	8.34	7.40	4.94	5.14	5.80	727.04	0.00	0.00	31.59
ZNXU	5.57	5.57	5.70	4.72	4.17	4.18	16.11	16.28	1.57	1.33	0.09	0.07	0.07	1136.09	4.99	4.99	4.99
GAXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.15	0.00	0.00	0.00	0.00
GAXU	19.86	19.84	20.30	16.82	14.87	14.90	57.40	58.01	5.60	4.75	0.27	0.22	0.22	22.75	17.76	17.76	17.76
ASXC	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ASXU	0.61	0.61	0.62	0.52	0.46	0.46	1.76	1.78	0.17	0.15	0.01	0.01	0.01	0.88	0.54	0.54	0.54
SEXC	7.26	0.00	0.24	0.00	3.12	0.00	10.83	0.00	0.00	1.21	0.00	0.00	0.03	0.00	8.84	0.00	11.19
SEXU	13.07	13.05	13.36	11.07	9.79	9.80	37.77	38.17	3.68	3.13	0.18	0.15	0.14	11.69	11.69	11.69	11.69
BRXC	10.54	0.00	0.00	2.98	2.63	0.67	0.00	0.00	0.00	0.73	0.00	0.02	0.07	5.87	3.52	0.00	5.49
BRXU	9.28	9.26	9.48	7.85	6.95	6.96	26.81	27.09	2.61	2.22	0.13	0.10	0.10	8.30	8.30	8.30	8.30
RBXC	1.31	3.46	0.00	0.36	0.00	0.00	0.00	17.92	0.00	0.73	0.00	0.00	0.03	10.98	0.00	0.00	4.27
RBXU	6.84	6.83	6.99	5.79	5.12	5.13	19.77	19.98	1.93	1.64	0.09	0.08	0.07	7.25	6.12	6.12	6.12
SRXC	0.00	0.89	4.45	2.58	4.91	9.21	3.79	2.60	2.97	0.94	0.43	0.30	0.22	5283.92	8.63	8.21	3.90
SRXU	12.37	12.35	12.64	10.47	9.26	9.28	35.74	36.12	3.48	2.96	0.17	0.14	0.13	63.43	11.06	11.06	11.06
YTXC	1.12	4.16	2.06	6.51	3.47	0.00	0.00	5.88	0.20	1.21	0.05	0.11	0.08	0.00	2.97	3.73	2.18
YTXU	9.28	9.26	9.48	7.85	6.95	6.96	26.81	27.09	2.61	2.22	0.13	0.10	0.10	8.88	8.30	8.30	8.30

U is designated for measurement uncertainty or limit of detection

TABLE D-1 (CONT'D.) ENGINE A METALS AND ELEMENTS

	FTP-w-1	FTP-w-2	FTP-w-3	FTP-wo-1	FTP-wo-2	FTP-wo-3	CARBx-1	CARBx-2	CARBz-1	CARBz-1	16-Hour-1	16-Hour-2	16-Hour-3	TB-1	TB-2	TB-3	TB-4
	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr
ZRXU	21.74	21.71	22.21	18.41	16.28	16.30	62.82	63.48	6.12	5.20	0.30	0.24	0.24	40.22	19.44	19.44	19.44
NBXC	0.00	0.00	6.27	3.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.03	10.98	0.00	6.28	11.40
NBXU	16.77	16.75	17.14	14.20	12.56	12.58	48.47	48.98	4.73	4.01	0.23	0.19	0.18	15.25	15.00	15.00	15.00
MOXC	2.44	0.00	11.01	0.00	4.14	0.00	0.00	3.28	0.00	0.06	0.00	0.06	0.00	0.00	0.00	8.04	6.12
MOXU	14.90	14.88	15.22	12.61	11.16	11.17	43.05	43.51	4.20	3.56	0.20	0.17	0.16	13.87	13.32	13.32	13.32
PDXC	12.27	0.00	4.93	0.00	0.00	0.00	0.00	0.00	1.23	1.68	0.00	0.00	0.03	0.00	0.00	0.00	0.00
PDXU	28.58	28.54	29.20	24.20	21.40	21.64	82.59	83.46	8.05	6.84	0.39	0.32	0.31	25.56	25.56	25.56	25.56
AGXC	0.00	4.16	5.60	6.86	0.49	0.81	0.00	0.00	0.00	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AGXU	26.05	26.01	26.62	22.06	19.50	19.54	75.28	76.07	7.34	6.23	0.36	0.29	0.28	23.29	23.29	23.29	23.29
CDXC	0.00	5.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CDXU	32.56	32.80	33.27	27.57	24.38	24.42	94.10	95.09	9.17	7.86	0.45	0.36	0.35	28.87	29.12	29.12	29.37
INXC	0.00	2.62	0.00	4.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.52	0.00	0.00	0.00
INXU	19.21	19.18	19.63	16.26	14.38	14.41	55.51	56.09	5.41	4.60	0.26	0.21	0.21	17.18	17.18	17.18	17.18
SNXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
SNXU	24.78	24.75	25.04	20.98	18.35	18.59	71.62	72.38	6.98	5.86	0.34	0.27	0.27	22.16	22.16	22.16	22.16
SBXC	0.00	0.00	0.00	33.60	0.00	0.00	46.30	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	32.34	0.00
SBXU	45.91	45.85	46.91	38.87	34.38	34.43	132.68	134.08	12.94	10.98	0.63	0.51	0.50	40.77	41.06	41.06	41.06
CSXC	7.21	0.00	0.00	3.89	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.03	0.04	0.00	0.59	0.00	0.00
CSXU	7.40	7.39	7.56	6.27	5.54	5.55	21.39	21.62	2.09	1.77	0.10	0.08	0.08	6.62	6.62	6.62	6.62
BAXC	1.31	0.00	0.00	0.00	0.00	1.65	0.00	0.00	0.37	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BAXU	3.70	3.70	3.78	3.13	2.77	2.78	10.70	10.81	1.04	0.89	0.05	0.04	0.04	1724.78	3.31	3.31	3.31
LAXC	0.00	0.00	5.60	0.00	0.00	0.00	0.68	13.41	0.30	0.00	0.00	0.00	0.00	0.00	0.96	4.90	0.00
LAXU	5.57	5.57	5.70	4.72	4.17	4.18	16.11	16.28	1.57	1.33	0.08	0.06	0.06	4.99	4.99	4.99	4.99
CEXC	1.36	0.89	0.00	0.00	4.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CEXU	8.10	8.09	8.28	6.86	6.07	6.08	23.42	23.67	2.28	1.94	0.11	0.09	0.09	7.25	7.25	7.25	7.25
SMXC	4.17	0.00	0.00	9.08	8.03	0.00	23.42	27.50	0.67	2.15	0.00	0.00	0.00	0.00	0.00	6.45	8.42
SMXU	11.15	11.13	11.39	9.44	8.35	8.36	32.22	32.56	3.14	2.67	0.15	0.12	0.12	16.93	9.97	9.97	9.97
EUXC	0.00	0.00	4.26	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	13.11	2.93	0.00
EUXU	40.29	40.24	41.17	34.11	30.17	30.22	116.43	117.66	11.35	9.64	0.55	0.45	0.44	50.44	36.32	36.03	36.03
TBXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.89	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00
TBXU	13.63	13.61	13.93	11.54	10.21	10.22	39.40	39.81	3.84	3.26	0.19	0.16	0.15	14.12	12.19	12.19	12.19
HFXC	0.00	3.56	23.31	6.35	0.00	30.92	142.02	0.00	8.53	16.06	0.00	0.08	0.32	0.00	0.00	0.00	0.00
HFXU	88.35	87.91	89.95	74.53	65.91	66.02	255.34	257.08	24.80	21.14	1.21	0.98	0.96	90.12	78.72	78.72	78.47
TAXC	0.00	42.48	0.00	57.56	47.60	39.81	172.35	65.40	18.90	0.00	0.00	0.26	0.21	0.00	39.22	15.29	21.20
TAXU	74.11	73.69	75.73	62.75	55.50	55.59	214.19	215.48	20.88	17.73	1.02	0.82	0.80	74.03	65.99	65.99	65.99
WOXC	47.17	0.00	0.00	8.01	0.00	0.00	0.00	0.00	0.00	0.90	1.06	0.00	0.00	0.00	0.00	46.13	16.30
WOXU	106.53	106.06	108.52	90.20	79.52	79.65	306.93	310.16	29.83	25.49	1.46	1.18	1.15	105.66	95.53	95.27	95.27
IRXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.98	16.09
IRXU	22.91	22.88	23.41	19.40	17.15	17.18	66.21	66.90	6.45	5.48	0.31	0.25	0.25	20.49	20.49	20.49	20.78
AUXC	4.59	0.00	9.19	0.95	16.59	32.08	0.00	21.21	6.24	0.00	0.00	0.38	0.20	0.00	0.00	0.00	0.00
AUXU	48.95	48.89	50.02	41.45	36.90	36.96	141.48	142.97	13.89	11.71	0.67	0.55	0.54	43.78	43.78	43.78	43.78
HGXC	0.00	0.00	0.00	0.00	0.00	0.98	0.00	0.00	0.00	0.21	0.19	0.00	0.00	0.00	0.00	6.66	0.00
HGXU	14.90	14.88	15.22	12.61	11.16	11.17	43.05	43.51	4.29	3.56	0.20	0.17	0.16	13.32	13.32	13.32	13.32
TLXC	0.00	0.65	2.01	0.91	0.49	0.00	0.00	30.10	1.91	1.10	0.00	0.00	0.00	4.32	0.00	12.36	0.21
TLXU	15.51	15.49	15.84	13.13	11.61	11.63	44.81	45.29	4.37	3.71	0.21	0.17	0.17	13.87	13.87	13.87	13.87
PBXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	293.33	9.40	0.00	0.00	0.24	0.02	0.00	0.00	0.00	0.00
PBXU	16.11	16.09	16.47	13.65	12.07	12.09	46.57	48.02	4.63	3.86	0.22	0.18	0.18	15.00	14.41	14.41	14.41
URXC	0.00	8.33	0.00	0.00	8.21	10.86	41.84	69.23	0.00	3.88	0.00	0.00	0.00	0.00	3.52	0.00	0.00
URXU	26.05	26.01	26.62	22.06	19.50	19.54	75.28	76.07	7.34	6.23	0.36	0.29	0.29	24.38	23.29	23.29	23.29

U is designated for measurement uncertainty or limit of detection

TABLE D-2. ENGINE B METALS AND ELEMENTS

	FTP-w-1	FTP-w-2	FTP-w-3	FTP-wo-1	FTP-wo-2	FTP-wo-3	CARBx-1	CARBx-2	CARBz-1	CARBz-2	16-Hour-1	16-Hour-2	16-Hour-3	TB-1	TB-2	TB-3	TB-4
	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr
NAXC	0.00	0.00	0.00	110.12	0.00	0.00	56.42	0.00	62.09	0.00	33.52	30.82	33.25	0.00	0.00	0.00	36.41
NAXU	315.30	296.94	283.96	309.43	305.50	304.34	653.12	637.27	89.06	91.04	6.57	6.51	6.52	303.40	303.93	299.94	304.67
MGXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.78	1.69	3.55	0.00	0.00	0.00	0.00
MGXU	168.01	159.00	151.04	163.63	163.98	162.95	346.84	341.24	46.65	48.59	3.17	3.15	3.14	161.71	161.71	161.54	161.71
ALXC	14.59	37.29	0.00	47.69	15.81	0.00	24.47	0.00	0.00	0.94	4.47	2.13	2.31	0.00	0.00	0.00	29.82
ALXU	27.85	26.55	24.88	27.23	27.18	27.04	57.37	56.56	7.73	8.05	0.54	0.53	0.52	26.75	26.58	26.58	26.94
SIXC	0.00	0.00	15.91	17.69	0.00	0.00	0.00	0.00	0.00	0.00	0.95	0.80	0.67	0.00	1.19	0.00	0.00
SIXU	31.02	29.36	28.07	30.31	30.27	30.12	63.49	63.00	8.60	8.96	0.58	0.58	0.57	29.79	29.79	29.79	29.60
PHXC	53.30	48.40	50.59	55.41	53.09	42.61	101.50	135.14	11.12	16.57	22.77	16.95	22.03	61.06	50.17	60.28	41.87
PHXU	9.08	8.59	8.32	8.98	8.86	8.82	18.71	18.79	2.52	2.67	0.26	0.24	0.26	8.89	8.72	8.89	8.72
SUXC	1247.19	1177.98	1137.19	1212.49	1244.08	1096.54	2475.93	2668.93	337.06	350.41	498.22	356.97	490.77	1170.96	1094.78	1179.79	1168.38
SUXU	30.59	28.95	27.50	29.69	30.11	29.08	62.60	62.65	8.43	8.78	3.35	2.51	3.31	29.19	28.99	29.38	29.19
CLXC	0.00	4.09	0.00	0.00	0.00	1.06	0.00	0.00	0.01	0.24	0.00	0.11	0.00	0.00	40.18	0.00	0.00
CLXU	6.11	5.78	5.49	5.93	5.96	5.93	12.59	12.41	1.70	1.77	0.11	0.11	0.11	5.87	6.06	5.87	5.87
KPXC	4.30	7.91	11.87	13.60	1.83	4.45	9.44	7.08	1.27	2.02	0.65	0.33	0.42	7.50	36.02	3.88	3.88
KPXU	5.71	5.40	5.13	5.54	5.57	5.54	11.76	11.59	1.58	1.65	0.11	0.11	0.11	5.48	5.48	5.48	5.48
CAXC	107.01	71.64	68.29	107.55	62.04	60.13	143.13	140.58	20.85	19.69	5.64	5.00	4.81	101.21	67.54	63.91	59.23
CAXU	7.06	6.68	6.35	6.86	6.89	6.86	14.55	14.34	1.96	2.04	0.13	0.13	0.13	6.78	6.78	6.78	6.78
SCXC	0.00	0.00	0.00	1.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SCXU	22.52	21.31	20.24	21.86	21.97	21.86	46.38	45.73	6.25	6.50	0.42	0.42	0.41	21.63	21.63	21.63	21.63
TIXC	1.87	0.76	0.00	0.00	2.36	0.00	4.39	4.92	0.00	0.31	0.31	0.04	0.10	2.58	1.27	2.33	1.55
TIXU	4.21	3.98	3.78	4.09	4.11	4.09	8.67	8.55	1.17	1.22	0.08	0.08	0.08	4.04	4.04	4.04	4.04
VAXC	0.00	1.01	0.00	0.00	0.00	0.00	0.53	0.00	0.00	0.00	0.01	0.00	0.01	0.53	0.78	0.25	0.00
VAXU	0.37	0.35	0.34	0.36	0.37	0.36	0.77	0.76	0.10	0.11	0.01	0.01	0.01	0.36	0.36	0.36	0.36
CRXC	21.19	21.33	25.11	26.59	23.58	26.59	50.30	57.26	6.48	6.59	0.51	0.67	0.68	29.16	21.65	20.60	21.65
CRXU	3.83	3.63	3.45	3.72	3.74	3.72	7.90	7.79	1.06	1.11	0.07	0.07	0.07	3.68	3.68	3.68	3.68
MNXC	5.68	5.37	5.11	0.00	3.97	14.95	0.00	12.06	2.62	0.00	0.31	0.54	0.21	12.18	11.93	5.45	5.21
MNXU	8.04	7.61	7.23	7.81	7.85	7.81	16.57	16.34	2.23	2.32	0.15	0.15	0.15	7.73	7.73	7.73	7.73
FEXC	152.19	128.96	136.32	141.18	136.43	139.13	292.38	295.92	41.02	45.14	13.14	18.31	19.39	160.44	136.07	124.16	132.19
FEXU	10.70	9.93	9.61	10.19	10.24	10.19	21.62	21.31	2.91	3.09	0.21	0.22	0.22	10.27	10.08	10.08	10.08
COXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COXU	0.37	0.35	0.34	0.36	0.37	0.36	0.77	0.76	0.10	0.11	0.01	0.01	0.01	0.36	0.36	0.36	0.36
NIXC	6.37	8.84	7.65	6.97	12.80	8.54	19.24	15.11	3.04	3.31	0.23	0.25	0.26	10.00	7.67	8.69	7.39
NIXU	1.90	1.80	1.71	1.85	1.86	1.85	3.92	3.86	0.53	0.55	0.04	0.04	0.04	1.83	1.83	1.83	1.83
CUXC	12.83	8.57	14.44	62.21	16.99	30.79	34.74	22.19	4.38	3.39	0.32	0.48	0.33	18.52	15.42	14.12	28.63
CUXU	3.43	3.25	3.08	3.53	3.35	3.33	7.07	6.97	0.95	0.99	0.06	0.06	0.06	3.30	3.30	3.30	3.30
ZNXC	15.51	14.43	34.34	53.56	13.56	26.06	25.83	36.48	5.28	4.17	0.86	0.93	0.97	18.03	22.15	14.90	28.38
ZNXU	3.43	3.25	3.27	3.53	3.35	3.33	7.07	6.97	0.95	0.99	0.07	0.07	0.07	3.30	3.30	3.30	3.30
GAXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	1.97	1.97	0.00	0.00
GAXU	12.22	11.57	10.99	11.87	11.93	11.87	25.18	24.83	3.39	3.53	0.23	0.23	0.23	11.74	11.74	11.74	11.74
ASXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ASXU	0.37	0.35	0.34	0.36	0.37	0.36	0.77	0.76	0.10	0.11	0.01	0.01	0.01	0.36	0.36	0.36	0.36
SEXC	0.00	1.15	5.47	2.24	0.00	8.79	12.53	6.32	0.00	0.00	0.00	0.06	0.00	8.42	4.02	0.00	5.59
SEXU	8.04	7.61	7.23	7.81	7.85	7.81	16.57	16.34	2.23	2.32	0.15	0.15	0.15	7.73	7.73	7.73	7.73
BRXC	0.00	0.00	5.34	1.57	0.00	4.45	0.00	0.00	0.38	0.23	0.00	0.00	0.06	2.33	7.78	0.00	1.02
BRXU	5.71	5.40	5.13	5.54	5.57	5.54	11.76	11.59	1.58	1.65	0.11	0.11	0.11	5.48	5.48	5.48	5.48
RBXC	0.00	1.53	0.00	1.82	0.51	1.82	0.00	14.75	0.00	0.00	0.00	0.00	0.02	0.50	1.55	0.00	0.00
RBXU	4.21	3.98	3.78	4.09	4.11	4.09	8.67	8.55	1.17	1.22	0.08	0.08	0.08	4.04	4.04	4.04	4.04
SRXC	5.13	13.01	3.16	0.00	4.73	0.78	1.66	6.03	2.54	0.31	0.20	0.09	0.10	4.65	7.25	5.95	3.38
SRXU	7.61	7.20	6.84	7.39	7.43	7.39	15.68	15.46	2.11	2.20	0.14	0.14	0.14	7.31	7.31	7.31	7.31
YTXC	0.00	2.43	0.39	0.00	0.00	1.46	0.00	1.41	1.24	0.90	0.00	0.09	0.10	0.00	1.97	0.00	1.44
YTXU	5.71	5.40	5.13	5.54	5.57	5.54	11.76	11.59	1.58	1.65	0.11	0.11	0.11	5.48	5.48	5.48	5.48

U is designated for measurement uncertainty or limit of detection

TABLE D-2 (CONT'D.) ENGINE B METALS AND ELEMENTS

	FTP-w-1	FTP-w-2	FTP-w-3	FTP-wo-1	FTP-wo-2	FTP-wo-3	CARBx-1	CARBx-2	CARBz-1	CARBz-2	16-Hour-1	16-Hour-2	16-Hour-3	TB-1	TB-2	TB-3	TB-4
	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr
ZRXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.14
ZRXU	13.38	12.66	12.03	12.98	13.06	12.99	27.56	27.17	3.71	3.86	0.25	0.25	0.25	12.85	12.85	12.85	12.85
NBXC	1.10	2.05	5.60	0.00	0.00	0.00	10.04	1.64	2.02	0.00	0.00	0.14	0.00	0.00	0.00	0.28	0.00
NBXU	10.32	9.77	9.28	10.02	10.07	10.02	21.26	20.96	2.86	2.98	0.19	0.19	0.19	9.91	9.91	9.91	9.91
MOXC	0.00	0.00	4.98	0.00	0.00	0.00	14.19	0.29	0.00	0.00	0.00	0.00	0.00	0.42	0.00	0.14	0.00
MOXU	9.17	8.68	8.24	8.90	8.95	8.90	18.89	18.62	2.54	2.65	0.17	0.17	0.17	8.81	8.81	8.81	8.81
PDXC	0.00	3.82	12.13	9.68	7.09	0.00	7.19	0.00	0.00	0.00	0.00	0.00	0.25	0.00	12.18	5.43	4.15
PDXU	17.59	16.64	15.81	17.07	17.16	17.08	36.23	35.72	4.88	5.08	0.33	0.33	0.32	16.89	16.89	16.89	16.89
AGXC	5.25	0.00	6.43	6.41	0.00	0.00	0.00	30.39	0.00	2.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AGXU	16.03	15.17	14.41	15.56	15.64	15.56	33.02	32.55	4.45	4.63	0.30	0.30	0.30	15.40	15.40	15.40	15.40
CDXC	0.00	0.00	0.00	0.00	0.00	0.00	1.13	0.00	0.00	0.00	0.00	0.00	0.00	3.66	0.00	0.00	3.66
CDXU	20.04	18.96	18.17	19.45	19.55	19.46	41.63	40.69	5.56	5.79	0.37	0.37	0.37	19.41	19.24	19.24	19.41
INXC	0.00	0.00	8.50	0.00	0.00	0.25	7.25	12.06	0.38	2.42	0.00	0.00	0.00	0.00	10.88	5.70	0.00
INXU	11.82	11.19	10.63	11.47	11.54	11.48	24.35	24.01	3.28	3.41	0.22	0.22	0.22	11.35	11.35	11.35	11.35
SNXC	0.00	0.00	0.00	0.00	0.00	0.28	18.95	0.00	3.45	1.49	0.00	0.15	0.00	0.00	3.13	0.00	0.00
SNXU	15.25	14.43	13.71	14.80	14.88	14.81	31.42	30.62	4.23	4.41	0.28	0.28	0.28	14.48	14.65	14.65	14.65
SBXC	0.00	3.71	13.48	0.00	0.00	0.00	53.10	1.35	3.48	3.16	0.00	0.20	0.00	6.34	3.77	0.00	12.57
SBXU	28.43	26.74	25.40	27.42	27.74	27.43	58.20	57.38	7.84	8.16	0.52	0.52	0.52	27.14	27.14	27.30	27.14
CSXC	0.00	0.38	0.00	1.43	0.00	0.00	3.62	0.00	0.00	0.00	0.00	0.04	0.03	0.00	0.00	1.16	0.00
CSXU	4.55	4.31	4.09	4.42	4.45	4.42	9.38	9.25	1.26	1.32	0.08	0.08	0.08	4.38	4.38	4.38	4.38
BAXC	0.00	0.00	0.00	0.00	0.25	0.00	3.86	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
BAXU	2.28	2.16	2.05	2.21	2.22	2.21	4.69	4.63	0.63	0.66	0.04	0.04	0.04	2.19	2.19	2.19	2.19
LAXC	0.40	0.90	0.36	0.00	0.00	0.39	0.00	0.00	0.00	0.00	0.01	0.01	0.04	2.19	0.00	0.64	0.00
LAXU	3.43	3.25	3.08	3.33	3.35	3.33	7.07	6.97	0.95	0.99	0.06	0.06	0.06	3.30	3.30	3.30	3.30
CEXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	4.68	0.00	0.00	0.00
CEXU	4.99	4.72	4.48	4.84	4.87	4.84	10.27	10.13	1.38	1.44	0.09	0.09	0.09	4.79	4.79	4.79	4.79
SMXC	6.60	3.71	2.05	0.00	0.00	0.00	5.82	12.35	0.26	0.00	0.00	0.00	0.00	1.94	5.84	3.24	0.00
SMXU	6.86	6.49	6.17	6.66	6.70	6.66	14.13	13.94	1.90	1.98	0.13	0.13	0.13	6.59	6.59	6.59	6.59
EUXC	0.00	0.00	0.00	2.74	0.00	0.00	39.73	26.58	0.00	0.00	0.00	0.06	0.00	0.00	0.00	6.34	0.00
EUXU	24.79	23.46	22.29	24.07	24.20	24.07	51.49	50.76	6.88	7.16	0.46	0.46	0.46	23.81	23.81	24.01	23.81
TBXC	0.00	6.63	0.00	0.00	0.00	0.00	2.73	9.84	0.00	0.00	0.00	0.00	0.00	0.00	4.13	4.13	0.00
TBXU	8.39	8.13	7.54	8.14	8.19	8.15	17.28	17.04	2.33	2.42	0.16	0.16	0.16	8.06	8.06	8.06	8.06
HFXC	0.00	31.95	0.00	13.12	16.88	7.36	98.41	0.00	0.00	0.00	0.48	0.00	0.00	0.00	0.00	22.82	16.09
HFXU	54.17	51.45	48.70	52.58	52.87	52.60	112.01	109.67	15.03	15.65	1.01	1.01	0.99	52.22	51.86	52.03	52.03
TAXC	0.00	19.42	11.40	24.88	22.40	0.00	80.59	9.31	12.58	0.00	0.00	0.48	0.28	27.99	13.24	0.00	17.89
TAXU	45.61	42.97	40.82	44.08	44.31	44.09	93.96	92.22	12.65	13.12	0.84	0.84	0.84	43.61	43.61	43.81	43.61
WOXC	0.00	0.00	0.00	0.00	0.00	10.89	46.44	37.59	0.00	0.00	0.00	0.00	0.00	12.60	11.05	0.00	0.00
WOXU	65.35	61.85	58.75	63.25	63.78	63.66	135.05	133.14	18.13	18.88	1.21	1.21	1.20	62.97	62.97	62.77	62.77
IRXC	0.00	10.20	0.00	0.00	0.00	10.22	0.00	9.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.73	0.00
IRXU	14.10	13.53	12.85	13.68	13.76	13.88	29.04	28.63	3.91	4.07	0.26	0.26	0.26	13.54	13.54	13.54	13.54
AUXC	12.54	0.00	0.00	0.00	3.83	0.00	0.00	0.00	1.16	0.00	0.56	0.00	0.02	0.00	0.00	0.00	0.00
AUXU	30.33	28.51	27.08	29.44	29.40	29.25	62.06	61.19	8.36	8.70	0.56	0.56	0.55	28.94	28.94	29.13	28.94
HGXC	0.00	0.00	0.00	0.00	5.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HGXU	9.17	8.68	8.24	8.90	8.95	8.90	18.89	18.62	2.54	2.65	0.17	0.17	0.17	8.81	8.81	8.81	8.81
TLXC	0.00	4.20	2.80	0.00	0.65	0.00	17.52	0.00	0.00	0.90	0.00	0.00	0.11	0.00	0.00	8.69	0.00
TLXU	9.54	9.03	8.58	9.26	9.31	9.27	19.66	19.38	2.65	2.76	0.18	0.18	0.18	9.17	9.17	9.17	9.17
PBXC	0.00	0.00	8.50	0.28	11.09	0.00	13.90	6.62	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.80	0.00
PBXU	9.92	9.39	8.92	9.63	9.68	9.63	20.43	20.14	2.75	2.87	0.18	0.18	0.18	9.53	9.53	9.53	9.53
URXC	0.00	11.49	11.40	8.90	8.95	0.00	0.00	10.95	1.58	2.11	0.00	0.23	0.00	14.26	0.00	0.00	0.00
URXU	16.20	15.17	14.41	15.56	15.64	15.56	33.38	32.55	4.45	4.63	0.30	0.30	0.30	15.40	15.56	15.56	15.40

U is designated for measurement uncertainty or limit of detection

TABLE D-3. ENGINE C METALS AND ELEMENTS

	FTP-w-1	FTP-w-2	FTP-w-3	FTP-wo-1	FTP-wo-2	FTP-wo-3	CARBx-1	CARBx-2	CARBz-1	CARBz-2	16-Hour-1	16-Hour-2	16-Hour-3	TB-1	TB-2	TB-3	TB-4
	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr
NAXC	147.77	0.00	0.00	0.00	0.00	0.00	937.75	255.16	0.00	237.48	6.14	12.54	2.55	0.00	0.00	306.48	220.65
NAXU	365.58	342.12	355.83	359.55	362.01	361.55	834.78	814.02	87.95	153.03	5.93	5.98	5.61	357.11	359.92	366.50	360.59
MGXC	12.69	31.70	0.00	0.00	63.14	0.00	433.37	148.30	10.14	61.17	2.73	1.78	2.85	24.87	0.00	69.72	270.86
MGXU	191.79	182.10	191.05	191.65	194.20	191.00	434.09	428.33	47.32	78.79	3.09	3.06	2.98	190.54	190.13	190.99	191.31
ALXC	10.06	28.62	0.00	17.79	0.00	0.00	89.38	159.62	2.33	8.79	2.42	2.37	1.40	0.00	0.00	44.37	56.98
ALXU	31.91	30.51	31.85	31.95	32.27	31.69	72.31	72.18	7.86	13.14	0.52	0.52	0.50	31.70	31.70	31.92	31.83
SIXC	18.86	25.54	0.61	34.37	29.08	16.71	82.08	166.86	14.63	15.04	1.96	2.00	1.44	32.24	21.48	50.37	54.52
SIXU	35.28	33.50	35.03	35.33	35.68	35.29	79.40	79.27	8.76	14.43	0.57	0.57	0.56	35.05	35.05	35.31	35.40
PHXC	0.00	0.00	0.00	0.00	0.00	1.06	26.03	67.88	11.77	9.79	0.56	7.16	1.37	0.00	6.61	19.79	9.07
PHXU	10.73	10.40	10.71	10.75	10.85	10.96	24.66	24.44	2.70	4.48	0.18	0.20	0.17	10.66	10.89	10.89	10.76
SUXC	32.77	225.43	161.70	163.14	125.08	199.77	457.74	253.80	66.43	81.15	8.91	161.09	35.42	182.12	163.70	131.77	333.20
SUXU	40.97	39.75	41.57	41.70	41.92	41.88	94.22	92.46	10.37	17.12	0.70	1.50	0.79	41.37	41.37	41.18	41.59
CLXC	0.00	4.39	6.48	3.09	0.00	0.61	38.98	22.72	18.66	6.82	0.21	0.92	3.00	4.60	2.46	8.91	15.67
CLXU	7.00	6.65	6.99	7.01	7.08	7.01	15.76	15.63	1.78	2.86	0.11	0.12	0.12	6.96	6.96	6.96	6.96
KPXC	0.00	0.00	0.00	0.00	0.00	0.00	14.61	13.76	1.68	4.55	0.76	0.53	0.58	6.13	5.84	5.24	5.71
KPXU	6.55	6.22	6.54	6.56	6.63	6.56	14.75	14.62	1.62	2.68	0.11	0.10	0.10	6.51	6.51	6.51	6.51
CAXC	16.07	2.04	6.16	6.50	3.12	10.22	73.76	62.07	33.29	14.79	4.67	5.73	4.38	19.66	25.51	26.72	62.79
CAXU	8.32	7.90	8.31	8.33	8.42	8.33	18.73	18.56	2.05	3.40	0.14	0.14	0.13	8.27	8.27	8.27	8.27
SCXC	0.00	0.00	9.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.64	0.00	0.00
SCXU	25.80	24.50	25.76	25.84	26.09	25.81	58.07	57.56	6.36	10.64	0.42	0.41	0.40	25.63	25.63	25.63	25.63
TIXC	7.10	2.04	0.00	3.41	5.00	6.17	24.37	20.71	3.58	4.05	0.32	0.21	0.15	0.00	7.05	10.76	9.23
TIXU	4.82	4.58	4.81	4.83	4.87	4.82	10.85	10.75	1.19	1.97	0.08	0.08	0.07	4.79	4.79	4.79	4.79
VAXC	0.00	0.00	0.93	0.00	2.50	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.61	2.46	3.38	0.00
VAXU	0.45	0.43	0.45	0.45	0.45	0.45	1.01	1.00	0.11	0.18	0.01	0.01	0.01	0.45	0.45	0.45	0.45
CRXC	6.20	5.00	9.59	8.69	8.16	10.86	44.54	37.99	4.66	6.33	0.61	0.37	0.28	11.68	14.78	26.43	15.67
CRXU	4.37	4.15	4.36	4.38	4.42	4.37	9.83	9.75	1.08	1.79	0.07	0.07	0.07	4.34	4.34	4.34	4.34
MNXC	0.45	0.00	0.00	5.73	0.00	4.47	7.30	27.24	2.02	4.99	0.25	0.00	0.08	0.45	8.14	3.51	6.77
MNXU	9.19	8.73	9.17	9.20	9.29	9.19	20.68	20.50	2.26	3.76	0.15	0.15	0.14	9.13	9.13	9.13	9.13
FEXC	63.68	64.59	45.68	76.16	57.84	65.25	139.85	67.59	28.11	29.19	6.31	4.56	4.20	65.73	70.32	52.83	93.37
FEXU	12.69	12.05	12.67	12.71	12.84	12.70	28.56	28.31	3.13	5.19	0.21	0.21	0.20	12.61	12.61	12.61	12.61
COXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COXU	0.45	0.43	0.45	0.45	0.45	0.45	1.01	1.00	0.11	0.18	0.01	0.01	0.01	0.45	0.45	0.45	0.45
NIXC	4.63	7.05	3.40	6.82	10.01	10.22	18.80	4.16	4.19	5.06	0.19	0.20	0.10	7.98	4.31	7.69	4.76
NIXU	2.18	2.07	2.18	2.19	2.21	2.19	4.92	4.87	0.54	0.89	0.04	0.03	0.03	2.17	2.17	2.17	2.17
CUXC	6.20	7.08	4.33	9.94	3.77	4.05	28.56	30.39	5.19	23.27	0.41	0.35	0.16	5.24	10.76	13.53	10.76
CUXU	3.95	3.75	3.95	3.96	4.00	3.95	8.89	8.82	0.97	1.71	0.06	0.06	0.06	3.93	3.93	3.93	3.93
ZNXC	9.74	8.08	6.03	8.21	3.61	6.04	35.14	23.80	15.73	19.16	0.67	0.63	0.55	8.75	7.82	12.74	6.29
ZNXU	3.95	3.75	3.95	3.96	4.00	3.95	8.89	8.82	1.03	1.71	0.07	0.07	0.06	3.93	3.93	3.93	3.93
GAXC	0.00	8.94	2.63	11.91	12.35	0.00	3.11	0.00	0.00	0.00	0.03	0.14	0.00	0.00	0.00	0.00	0.00
GAXU	14.01	13.30	13.99	14.03	14.17	14.21	31.53	31.25	3.45	5.73	0.22	0.22	0.22	13.92	13.92	13.92	13.92
ASXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ASXU	0.45	0.43	0.45	0.45	0.45	0.45	1.01	1.00	0.11	0.18	0.01	0.01	0.01	0.45	0.45	0.45	0.45
SEXC	2.02	7.78	14.66	0.00	3.61	6.98	0.36	0.00	0.00	1.33	0.05	0.11	0.00	5.39	0.00	1.09	9.39
SEXU	9.19	8.73	9.17	9.20	9.29	9.19	20.68	20.50	2.26	3.76	0.15	0.15	0.14	9.13	9.13	9.13	9.13
BRXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
BRXU	6.55	6.22	6.54	6.56	6.63	6.56	14.75	14.62	1.62	2.68	0.11	0.10	0.10	6.51	6.51	6.51	6.51
RBXC	0.00	5.86	3.40	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	5.52	0.00	0.00	4.92
RBXU	4.82	4.58	4.81	4.83	4.87	4.82	10.85	10.75	1.19	1.97	0.08	0.08	0.07	4.79	4.79	4.79	4.79
SRXC	8.06	0.31	4.01	0.00	8.16	3.73	0.00	0.00	0.61	0.00	0.00	0.14	0.00	0.00	9.54	0.00	0.00
SRXU	8.74	8.30	8.73	8.75	8.84	8.74	19.67	19.50	2.15	3.57	0.14	0.14	0.14	8.68	8.68	8.68	8.68
YTXC	5.11	1.04	0.00	0.00	3.61	1.09	0.00	0.00	0.00	0.00	0.00	0.06	0.05	0.00	4.15	0.00	0.00
YTXU	6.55	6.22	6.54	6.56	6.63	6.56	14.75	14.62	1.62	2.68	0.11	0.10	0.10	6.51	6.51	6.51	6.51

U is designated for measurement uncertainty or limit of detection

TABLE D-3 (CONT'D.) ENGINE C METALS AND ELEMENTS

	FTP-w-1	FTP-w-2	FTP-w-3	FTP-wo-1	FTP-wo-2	FTP-wo-3	CARBx-1	CARBx-2	CARBz-1	CARBz-2	16-Hour-1	16-Hour-2	16-Hour-3	TB-1	TB-2	TB-3	TB-4
	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr
ZRXC	2.15	0.00	0.00	0.00	10.30	10.19	26.47	8.24	9.75	1.77	0.24	0.05	0.06	1.53	20.27	18.13	0.00
ZRXU	15.33	14.55	15.30	15.35	15.50	15.33	34.49	34.19	3.82	6.27	0.25	0.24	0.24	15.23	15.23	15.23	15.23
NBXC	0.00	5.13	0.00	5.41	1.10	6.65	7.30	0.00	0.00	2.09	0.00	0.00	0.14	0.00	0.00	5.68	3.83
NBXU	11.82	11.23	11.80	11.84	11.96	11.83	26.61	26.38	2.91	4.83	0.19	0.19	0.18	11.75	11.75	11.75	11.75
MOXC	6.94	0.00	0.00	0.00	0.00	4.47	34.42	3.08	0.00	1.33	0.00	0.00	0.00	3.54	0.00	7.21	0.00
MOXU	10.51	9.98	10.49	10.52	10.63	10.51	23.65	23.44	2.59	4.30	0.17	0.17	0.16	10.44	10.44	10.44	10.44
PDXC	4.63	0.00	0.00	0.00	0.00	9.29	42.45	41.36	0.00	5.56	0.32	0.00	0.00	0.00	0.00	0.00	15.96
PDXU	20.11	19.10	20.30	20.14	20.34	20.12	45.27	44.87	4.96	8.22	0.32	0.32	0.31	19.98	19.98	19.98	19.98
AGXC	0.00	0.00	0.00	0.00	0.00	0.00	18.80	0.00	3.66	0.51	0.00	0.01	0.00	0.00	0.00	0.00	13.22
AGXU	18.35	17.42	18.32	18.37	18.56	18.35	41.29	40.93	4.52	7.50	0.29	0.29	0.28	18.23	18.23	18.23	18.23
CDXC	0.00	0.00	0.00	11.62	0.00	0.00	0.00	0.00	0.00	0.83	0.31	0.12	0.17	0.00	0.00	18.26	0.00
CDXU	22.72	21.57	22.90	22.75	22.98	22.73	51.13	50.67	5.60	9.29	0.37	0.36	0.35	22.57	22.57	22.79	22.57
INXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.27	0.00	0.00	0.00	0.00	5.20	0.00	0.00	0.00
INXU	13.53	12.84	13.50	13.55	13.68	13.53	30.44	30.18	3.40	5.53	0.22	0.22	0.21	13.44	13.44	13.44	13.44
SNXC	2.47	12.33	0.00	0.00	0.00	3.09	14.61	0.00	0.00	6.82	0.00	0.01	0.09	0.00	0.32	17.21	0.00
SNXU	17.38	16.50	17.13	17.18	17.58	17.39	39.12	38.78	4.23	7.11	0.27	0.28	0.27	17.05	17.27	17.27	17.27
SBXC	0.00	0.00	0.00	19.21	0.00	0.00	0.00	0.00	2.90	8.47	0.00	0.00	0.00	21.83	8.01	8.62	0.00
SBXU	32.36	30.72	32.30	32.40	32.72	32.37	72.82	72.18	7.97	13.23	0.52	0.52	0.50	32.15	32.15	32.15	32.15
CSXC	0.00	2.50	0.00	3.57	0.00	0.00	0.36	0.00	0.96	0.00	0.00	0.00	0.06	1.40	0.48	0.00	0.00
CSXU	5.24	4.97	5.23	5.24	5.30	5.24	11.79	11.68	1.29	2.14	0.08	0.08	0.08	5.20	5.20	5.20	5.20
BAXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BAXU	2.63	2.50	2.63	2.64	2.66	2.64	5.93	5.88	0.65	1.08	0.04	0.04	0.04	2.62	2.62	2.62	2.62
LAXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.04	0.00	0.00	0.00	0.00
LAXU	3.95	3.75	3.95	3.96	4.00	3.95	8.89	8.82	0.97	1.62	0.06	0.06	0.06	3.93	3.93	3.93	3.93
CEXC	0.93	0.00	0.00	0.00	0.00	0.00	11.86	11.75	0.46	2.02	0.00	0.00	0.04	0.00	0.00	2.46	0.00
CEXU	5.69	5.40	5.68	5.70	5.75	5.69	12.80	12.69	1.40	2.33	0.09	0.09	0.09	5.65	5.65	5.65	5.65
SMXC	4.34	1.46	0.00	2.80	7.51	0.00	7.01	0.00	0.00	2.15	0.11	0.05	0.00	1.24	4.31	0.00	0.00
SMXU	7.87	7.47	7.86	7.88	7.96	7.88	17.72	17.56	1.94	3.22	0.13	0.13	0.12	7.82	7.82	7.82	7.82
EUXC	0.00	17.94	16.39	2.19	12.84	0.00	0.00	0.00	2.22	1.41	0.21	0.00	0.00	11.40	0.00	4.02	0.00
EUXU	28.40	26.97	28.36	28.44	28.73	28.41	63.92	63.36	7.00	11.61	0.46	0.45	0.44	28.22	28.22	28.22	28.22
TBXC	7.55	0.73	8.79	3.86	0.00	9.42	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	4.79
TBXU	9.64	9.15	9.62	9.65	9.75	9.64	22.13	21.93	2.42	3.94	0.16	0.16	0.15	9.77	9.58	9.77	9.58
HFXC	0.00	0.00	0.00	0.00	0.00	3.86	0.00	0.00	0.00	0.00	0.00	0.87	0.86	0.00	7.53	0.00	0.00
HFXU	62.08	58.94	62.20	62.17	62.78	62.10	141.15	139.91	15.40	25.55	1.00	1.00	0.97	61.45	61.67	62.09	62.22
TAXC	0.00	0.00	0.00	0.00	0.00	0.00	16.34	0.00	6.06	13.83	0.00	0.00	0.00	0.00	0.00	0.00	32.88
TAXU	52.44	49.61	52.35	52.51	52.84	52.26	118.01	116.97	12.92	21.44	0.84	0.83	0.81	51.91	52.10	52.10	52.00
WOXC	40.81	39.33	33.04	36.23	45.04	17.94	148.89	98.63	0.00	12.01	0.00	0.00	0.00	66.97	0.00	0.00	0.00
WOXU	74.64	70.87	74.52	74.75	75.49	74.67	168.49	166.50	18.45	30.52	1.19	1.20	1.17	74.38	74.38	74.38	74.47
IRXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	12.58	0.00
IRXU	16.29	15.47	16.26	16.31	16.48	16.30	37.17	36.34	4.01	6.75	0.26	0.26	0.25	16.41	16.41	16.41	16.06
AUXC	17.48	3.69	14.98	0.00	6.73	0.00	72.02	10.75	3.70	0.00	0.00	0.05	0.36	8.14	0.00	21.96	28.73
AUXU	34.86	32.89	34.80	34.69	35.03	34.65	78.46	77.27	8.59	14.16	0.56	0.55	0.54	34.41	34.41	34.64	34.64
HGXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.99	0.00
HGXU	10.60	10.07	10.59	10.62	10.72	10.61	24.37	24.15	2.61	4.43	0.17	0.17	0.16	10.53	10.53	10.53	10.44
TLXC	0.00	0.00	1.25	0.00	0.00	0.00	9.04	0.00	2.06	0.00	0.00	0.00	0.00	3.70	0.00	0.00	4.44
TLXU	10.96	10.40	10.94	10.97	11.08	10.96	24.66	24.44	2.70	4.48	0.18	0.18	0.17	10.89	10.89	10.89	10.89
PBXC	0.00	6.16	17.90	0.00	12.51	2.15	69.57	33.11	2.82	6.44	0.59	0.50	0.00	0.00	3.67	5.84	12.29
PBXU	11.37	10.80	11.36	11.39	11.50	11.38	26.10	25.37	2.80	4.65	0.19	0.19	0.18	11.30	11.30	11.30	11.30
URXC	11.60	0.00	0.00	0.00	5.78	4.79	0.00	0.00	0.00	0.00	0.00	0.00	0.01	17.97	9.67	0.00	0.00
URXU	18.35	17.42	18.32	18.37	18.56	18.35	41.29	40.93	4.52	7.50	0.29	0.29	0.28	18.45	18.23	18.23	18.23
U is designated for measurement uncertainty or limit of detection																	

TABLE D-4. ENGINE D METALS AND ELEMENTS

	FTP-w-1	FTP-w-2	FTP-w-3	FTP-wo-1	FTP-wo-2	FTP-wo-3	CARBx-1	CARBx-2	CARBz-1	CARBz-2	16-Hour-1	16-Hour-2	16-Hour-3	TB-1	TB-2	TB-3
	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr
NAXC	416.96	295.45	284.72	152.45	94.98	444.53	1288.91	193.52	39.69	108.28	28.88	35.42	14.48	226.90	35.38	178.88
NAXU	296.90	293.62	293.13	306.73	301.75	319.56	691.51	719.99	89.77	78.79	6.35	6.44	6.05	300.74	296.92	299.84
MGXC	185.29	156.71	133.26	176.39	192.27	197.85	433.75	402.50	51.92	39.10	4.47	7.22	4.13	73.55	199.45	19.93
MGXU	154.60	153.95	153.60	162.68	160.63	166.40	356.64	383.25	47.67	41.01	3.09	3.08	3.09	157.99	158.89	157.65
ALXC	68.28	56.65	80.87	41.49	0.00	71.88	198.24	153.42	15.84	18.26	2.18	3.18	2.40	45.34	53.75	39.47
ALXU	25.78	25.70	25.67	26.93	26.40	27.74	59.88	63.97	7.95	6.84	0.52	0.52	0.52	26.28	26.46	26.28
SIXC	64.81	59.64	8.32	33.65	27.80	48.34	99.60	20.73	12.70	8.75	2.87	4.16	5.15	31.30	33.34	28.99
SIXU	28.67	28.58	28.37	29.98	29.60	30.86	66.14	70.71	8.84	7.57	0.58	0.58	0.59	29.25	29.25	29.25
PHXC	16.80	26.42	19.46	2.23	19.02	24.24	73.77	70.71	5.10	8.36	10.34	14.37	8.68	14.94	12.16	26.44
PHXU	8.71	8.69	8.68	8.98	9.05	9.38	20.10	21.62	2.69	2.31	0.21	0.23	0.20	8.95	8.95	8.95
SUXC	304.91	376.90	333.12	361.44	260.47	344.27	779.71	997.50	91.87	87.77	223.96	350.16	199.07	255.62	320.23	356.75
SUXU	33.89	34.15	33.93	35.86	34.84	36.48	78.60	85.02	10.45	9.00	1.87	2.61	1.73	34.43	34.80	34.99
CLXC	11.45	4.48	14.88	3.16	8.54	6.18	21.23	19.76	2.07	4.17	0.36	2.95	3.12	3.85	0.00	2.81
CLXU	5.64	5.62	5.61	5.93	5.86	6.07	13.00	13.99	1.74	1.50	0.11	0.12	0.12	5.79	5.79	5.79
KPXC	12.56	8.81	6.33	2.77	1.96	5.51	10.68	23.81	2.19	2.62	0.68	1.14	6.59	10.86	6.53	5.26
KPXU	5.27	5.26	5.25	5.55	5.48	5.68	12.17	13.09	1.63	1.40	0.11	0.11	0.12	5.41	5.41	5.41
CAXC	56.57	28.87	26.36	21.33	28.28	26.10	55.94	97.79	12.31	11.79	8.89	14.57	42.55	59.62	25.40	89.24
CAXU	6.70	6.68	6.67	7.05	6.96	7.21	15.45	16.62	2.06	1.78	0.14	0.15	0.21	6.87	6.87	6.87
SCXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SCXU	20.94	20.88	20.67	21.85	21.57	22.34	47.89	51.97	6.40	5.51	0.41	0.41	0.42	21.31	21.31	21.31
TIXC	15.93	0.00	3.99	0.00	3.89	6.71	15.51	15.46	1.62	2.31	0.28	0.94	1.87	8.44	8.95	3.85
TIXU	3.88	3.87	3.86	4.08	4.03	4.17	8.95	9.62	1.20	1.03	0.08	0.08	0.08	3.98	3.98	3.98
VAXC	0.00	0.00	2.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.06	0.00	0.00	0.00
VAXU	0.36	0.36	0.36	0.38	0.38	0.39	0.83	0.90	0.11	0.10	0.01	0.01	0.01	0.37	0.37	0.37
CRXC	11.71	8.94	18.85	9.17	6.74	16.61	26.42	29.07	2.61	3.90	0.50	0.38	2.37	12.53	8.71	10.48
CRXU	3.52	3.51	3.50	3.70	3.65	3.78	8.11	8.73	1.08	0.93	0.07	0.07	0.07	3.61	3.61	3.61
MNXC	9.95	0.75	1.98	0.00	2.85	8.04	0.60	0.00	1.08	0.00	0.04	0.06	0.82	0.00	8.95	1.04
MNXU	7.39	7.37	7.36	7.78	7.68	7.96	17.06	18.35	2.28	1.96	0.15	0.15	0.15	7.59	7.59	7.59
FEXC	26.63	27.04	42.87	31.94	34.11	19.03	34.47	80.27	5.45	12.62	7.11	8.79	64.20	51.34	16.11	93.22
FEXU	10.21	10.18	10.17	10.75	10.61	10.99	23.56	25.34	3.15	2.71	0.21	0.22	0.32	10.48	10.48	10.67
COXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COXU	0.36	0.36	0.36	0.38	0.38	0.39	0.83	0.90	0.11	0.10	0.01	0.01	0.01	0.37	0.37	0.37
NIXC	0.00	1.62	0.62	0.00	7.63	0.00	13.48	7.76	0.81	0.00	0.06	0.04	1.07	1.41	2.95	9.08
NIXU	1.76	1.75	1.75	1.85	1.83	1.89	4.06	4.36	0.54	0.47	0.04	0.03	0.04	1.80	1.80	1.80
CUXC	11.43	11.39	9.91	6.80	11.63	9.38	25.82	22.84	2.07	3.70	0.41	0.46	0.94	13.27	9.95	4.33
CUXU	3.18	3.17	3.17	3.35	3.30	3.42	7.34	7.89	0.98	0.84	0.06	0.06	0.07	3.26	3.26	3.26
ZNXC	6.08	11.78	7.80	6.67	7.87	6.01	26.66	24.96	4.49	3.40	1.71	2.36	7.04	8.55	9.32	8.28
ZNXU	3.18	3.17	3.17	3.35	3.30	3.42	7.34	7.89	0.98	0.84	0.07	0.07	0.08	3.26	3.26	3.26
GAXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.56	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00
GAXU	11.27	11.24	11.22	11.86	11.71	12.13	26.00	27.98	3.48	2.99	0.22	0.22	0.22	11.57	11.57	11.57
ASXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ASXU	0.36	0.36	0.36	0.38	0.38	0.39	0.83	0.90	0.11	0.10	0.01	0.01	0.01	0.37	0.37	0.37
SEXC	3.88	5.10	6.08	7.48	3.49	10.32	0.00	19.44	6.86	0.00	0.00	0.31	0.05	4.49	3.98	0.00
SEXU	7.39	7.37	7.36	7.78	7.68	7.96	17.06	18.35	2.28	1.96	0.15	0.15	0.15	7.59	7.59	7.59
BRXC	2.84	8.56	3.84	1.96	0.64	3.87	2.56	15.08	1.04	0.49	0.11	0.01	0.00	0.00	8.55	0.37
BRXU	5.27	5.26	5.25	5.55	5.48	5.68	12.17	13.09	1.63	1.40	0.11	0.10	0.11	5.41	5.41	5.41
RBXC	0.00	4.46	0.00	0.00	1.80	0.00	0.00	0.00	1.61	0.60	0.06	0.00	0.00	0.27	0.00	0.00
RBXU	3.88	3.87	3.86	4.08	4.03	4.17	8.95	9.62	1.20	1.03	0.08	0.08	0.08	3.98	3.98	3.98
SRXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.21	0.34	0.00	0.00	0.00
SRXU	7.03	7.01	7.00	7.40	7.31	7.57	16.22	17.45	2.17	1.87	0.14	0.14	0.14	7.22	7.22	7.22
YTXC	0.00	0.00	2.24	1.58	0.00	1.09	0.00	0.00	0.00	0.00	0.00	0.14	0.05	0.00	0.00	1.78

U is designated for measurement uncertainty or limit of detection

TABLE D-4 (CONT'D.) ENGINE D METALS AND ELEMENTS

	FTP-w-1	FTP-w-2	FTP-w-3	FTP-wo-1	FTP-wo-2	FTP-wo-3	CARBx-1	CARBx-2	CARBz-1	CARBz-2	16-Hour-1	16-Hour-2	16-Hour-3	TB-1	TB-2	TB-3
	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr
YTXU	5.27	5.26	5.25	5.55	5.48	5.68	12.17	13.09	1.63	1.40	0.11	0.10	0.11	5.41	5.41	5.41
ZRXC	0.00	4.97	11.92	7.62	0.00	6.98	2.92	16.75	0.85	0.00	0.00	0.00	0.72	0.00	7.67	8.44
ZRXU	12.33	12.29	12.28	12.98	12.81	13.27	28.45	30.61	3.80	3.27	0.25	0.24	0.25	12.66	12.66	12.66
NBXC	0.00	2.84	0.00	9.55	6.31	6.54	0.00	0.00	0.00	0.36	0.08	0.02	0.02	8.04	0.00	3.19
NBXU	9.51	9.49	9.47	10.01	9.88	10.24	21.95	23.61	2.93	2.53	0.19	0.19	0.19	9.77	9.77	9.77
MOXC	0.00	5.44	0.00	3.13	0.00	0.00	13.18	10.46	0.07	0.00	0.00	0.00	0.00	7.14	0.00	1.78
MOXU	8.45	8.43	8.42	8.90	8.78	9.10	19.50	20.98	2.61	2.24	0.17	0.17	0.17	8.68	8.68	8.68
PDXC	0.00	0.00	0.00	0.00	0.00	7.23	0.00	0.00	1.15	0.00	0.00	0.18	0.01	0.00	0.00	5.63
PDXU	16.18	16.13	16.12	17.22	17.00	17.42	37.33	40.17	4.99	4.30	0.32	0.32	0.32	16.80	16.62	16.62
AGXC	0.00	0.00	4.71	0.00	0.00	1.61	0.00	24.70	0.00	0.00	0.00	0.04	0.00	11.49	0.00	0.00
AGXU	14.76	14.72	14.70	15.53	15.34	15.89	34.05	36.64	4.61	3.92	0.29	0.29	0.30	15.16	15.16	15.16
CDXC	0.00	10.18	11.92	0.00	0.00	6.46	0.00	0.00	5.60	0.00	0.00	0.13	0.00	0.00	1.30	9.98
CDXU	18.28	18.22	18.38	19.42	18.99	19.67	42.16	45.81	5.69	4.85	0.36	0.36	0.36	18.95	18.77	18.77
INXC	0.00	0.00	0.00	0.79	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.20	0.08	0.00	0.00	0.00
INXU	10.88	10.85	10.84	11.45	11.52	11.72	25.11	27.01	3.36	2.89	0.22	0.22	0.22	11.18	11.18	11.18
SNXC	0.00	0.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SNXU	13.81	13.94	13.93	14.53	14.53	15.05	31.85	34.26	4.26	3.71	0.28	0.28	0.28	14.17	14.17	14.36
SBXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SBXU	26.03	25.95	25.93	27.39	27.05	28.02	60.06	64.61	8.03	6.91	0.52	0.52	0.52	26.73	26.73	26.73
CSXC	0.00	0.00	1.75	0.00	0.00	0.00	0.00	3.14	0.23	0.07	0.00	0.00	0.00	1.30	0.00	0.00
CSXU	4.21	4.20	4.20	4.43	4.38	4.54	9.72	10.46	1.30	1.12	0.08	0.08	0.08	4.33	4.33	4.33
BAXC	0.00	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BAXU	2.12	2.11	2.11	2.23	2.20	2.28	4.89	5.26	0.65	0.56	0.04	0.04	0.04	2.18	2.18	2.18
LAXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LAXU	3.18	3.17	3.17	3.35	3.30	3.42	7.34	7.89	0.98	0.84	0.06	0.06	0.06	3.26	3.26	3.26
CEXC	0.00	0.00	2.11	2.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.08	0.00	0.00	2.44
CEXU	4.58	4.56	4.56	4.82	4.75	4.93	10.56	11.36	1.41	1.22	0.09	0.09	0.09	4.70	4.70	4.70
SMXC	2.61	6.31	4.09	4.33	5.80	6.01	5.43	0.00	0.65	0.00	0.04	0.00	0.00	0.00	1.41	6.26
SMXU	6.33	6.31	6.31	6.67	6.58	6.82	14.61	15.72	1.95	1.68	0.13	0.13	0.13	6.50	6.50	6.50
EUXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	4.46
EUXU	22.85	22.78	22.76	24.05	23.74	24.60	52.72	56.72	7.05	6.07	0.46	0.46	0.46	23.46	23.46	23.65
TBXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00
TBXU	7.91	7.89	7.88	8.32	8.06	8.51	18.25	19.63	2.44	2.10	0.16	0.15	0.16	8.12	8.12	8.12
HFXC	0.00	13.25	0.00	41.49	12.52	0.00	89.76	0.00	0.00	10.33	0.00	0.03	0.61	0.00	0.00	0.00
HFXU	50.57	50.05	50.18	52.83	52.16	54.23	115.82	125.06	15.59	13.33	1.00	0.99	1.00	51.73	51.73	51.18
TAXC	0.00	0.00	0.00	36.64	0.00	19.56	27.02	60.51	0.00	0.00	0.05	0.00	0.00	0.00	0.00	24.26
TAXU	41.93	41.81	41.76	44.32	43.76	45.33	97.15	104.52	13.04	11.23	0.84	0.83	0.84	43.24	43.05	43.24
WOXC	0.00	0.00	0.00	0.00	0.00	4.03	0.00	147.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WOXU	60.32	60.13	60.42	63.47	62.67	65.14	139.14	150.59	18.60	16.07	1.20	1.19	1.21	61.93	61.93	61.93
IRXC	1.37	0.00	10.27	0.00	1.93	0.95	9.48	1.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.58
IRXU	13.00	12.96	12.95	13.90	13.51	14.00	30.00	32.27	4.01	3.51	0.26	0.26	0.26	13.35	13.35	13.35
AUXC	14.32	0.00	0.00	1.47	20.55	18.37	3.22	4.04	3.11	5.85	0.34	0.00	0.53	23.39	6.26	0.00
AUXU	27.87	27.97	27.75	29.33	29.14	30.19	64.29	69.17	8.59	7.45	0.56	0.55	0.56	28.80	28.61	28.61
HGXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HGXU	8.45	8.43	8.42	8.90	8.78	9.10	19.50	20.98	2.61	2.29	0.17	0.17	0.17	8.87	8.68	8.68
TLXC	7.34	2.11	0.00	6.67	7.09	5.20	3.70	0.00	0.00	0.00	0.13	0.11	0.08	3.19	0.37	0.00
TLXU	8.82	8.79	8.78	9.28	9.16	9.49	20.34	21.88	2.72	2.34	0.18	0.17	0.18	9.05	9.05	9.05
PBXC	1.24	3.71	3.96	0.00	1.02	11.52	16.04	8.02	4.45	4.16	0.01	0.00	0.13	8.41	11.73	0.00
PBXU	9.15	9.12	9.11	9.63	9.51	9.85	21.11	22.71	2.82	2.43	0.18	0.18	0.18	9.40	9.40	9.40
URXC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.17	0.00	0.00	0.00	7.03
URXU	14.76	14.72	14.70	15.53	15.34	15.89	34.05	36.64	4.55	3.92	0.29	0.29	0.30	15.16	15.16	15.16

U is designated for measurement uncertainty or limit of detection

APPENDIX E

CARBONYL COMPOUNDS AND ALCOHOLS

TABLE E-1. ENGINE A CARBONYLS AND ALCOHOLS

mg/hp-hr	FTP-w-1	FTP-w-2	FTP-w-3	FTP-wo-1	FTP-wo-2	FTP-wo-3	CARBX-1	CARBX-2	CARBZ-1	CARBZ-2	16-hour-1a	16-Hour-1b	16-hour-2a	16-hour-2b	16-hour-3a	16-hour-3b	TB-1	TB-2	TB-3	TB-4
Methanol	0.00	0.00	0.00	0.00	0.00	0.00	10.26	4.66	0.00	0.00	0.00	0.14	0.05	0.01	0.00	0.35	0.00	0.00	0.00	0.00
Ethanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00
2-Propanol	0.00	0.00	0.00	0.00	0.00	0.00	18.20	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.06	0.00	3.07	3.07	1.04	0.00
1-Propanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1-Butanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Formaldehyde	0.00	0.00	0.00	0.00	0.00	0.00	124.37	111.95	0.60	0.87	3.76	2.88	0.77	0.00	1.95	0.75	1.76	1.76	0.00	0.00
Acetaldehyde	0.25	0.12	0.07	0.14	0.06	0.19	56.77	51.23	0.47	0.38	1.35	2.04	0.66	0.00	0.67	0.38	0.09	0.09	0.00	0.00
Acrolein	0.00	0.00	0.00	0.00	0.00	0.00	11.35	8.16	0.02	0.04	0.09	0.15	0.00	0.31	0.00	0.45	0.00	0.00	0.00	0.00
Acetone	0.00	0.04	0.00	1.53	0.16	0.00	122.75	116.35	8.48	7.48	0.00	0.00	0.00	0.00	0.00	2.82	0.00	0.00	0.00	0.00
Propionaldehyde	0.00	0.00	0.00	0.00	0.00	0.00	11.90	11.43	0.25	0.22	0.14	0.14	0.11	0.00	0.00	0.10	0.00	0.00	0.00	0.00
Crotonaldehyde	0.00	0.00	0.00	0.11	0.00	0.00	3.61	6.23	0.00	0.09	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Isobutyraldehyde	0.00	0.00	0.00	0.00	0.00	0.00	4.58	2.76	0.09	0.07	0.02	0.02	0.00	0.05	0.00	0.03	0.00	0.00	0.00	0.00
MEK	0.00	0.00	0.00	0.00	0.00	0.00	4.58	2.76	0.09	0.07	0.02	0.02	0.00	0.05	0.00	0.03	0.00	0.00	0.00	0.00
Benzaldehyde	0.00	0.00	0.00	0.02	0.00	0.00	4.07	3.34	0.17	0.06	0.22	0.54	0.34	0.00	0.09	0.71	0.96	0.96	0.00	0.00
Isovaleraldehyde	0.00	0.00	0.00	0.00	0.00	0.00	2.66	2.11	0.01	0.01	0.09	0.18	0.00	0.00	0.00	0.00	0.05	0.05	0.00	0.00
Valeraldehyde	0.00	0.00	0.00	0.00	0.00	0.00	3.86	3.61	0.09	0.05	0.06	0.06	0.04	0.00	0.00	0.03	0.00	0.00	0.00	0.00
o-Tolualdehyde	0.00	0.00	0.00	0.00	0.00	0.00	1.37	0.78	0.01	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
m/p-Tolualdehyde	0.00	0.00	0.00	0.00	0.00	0.00	3.60	3.35	0.27	0.17	0.25	0.40	0.52	0.00	0.11	0.04	0.00	0.00	0.00	0.00
Hexanaldehyde	0.00	0.00	0.00	0.00	0.00	0.00	1.06	0.86	0.07	0.00	0.14	0.15	0.01	0.00	0.04	0.00	0.00	0.00	0.00	0.00
Dimethylbenzaldehyde	0.00	0.00	0.00	0.00	0.00	0.00	3.14	0.10	0.07	0.01	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nominal Limit of Detection	0.60	0.60	0.60	0.60	0.60	0.60	1.77	1.77	0.77	0.77	0.01	0.01	0.01	0.01	0.01	0.01	0.60	0.60	0.60	0.60

Footnotes: Negative values are due to background subtraction
Zero is reported if measurement is below the blank value

TABLE E-2. ENGINE B CARBONYLS AND ALCOHOLS

mg/hp-hr	FTP-w-1	FTP-w-2	FTP-w-3	FTP-wo-1	FTP-wo-2	FTP-wo-3	CARBX-1	CARBX-2	CARBZ-1	CARBZ-2	16-hour-1a	16-hour-1b	16-hour-2a	16-hour-2b	16-hour-3a	16-hour-3b	TB-1	TB-2	TB-3	TB-4
Methanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	-0.15	0.00	-0.17	-0.06	0.00	0.00	0.00	0.00
Ethanol	0.00	0.00	0.00	0.00	0.00	0.00	-0.22	-0.71	0.00	0.00	0.00	0.00	-0.16	-0.11	0.12	-0.02	0.00	0.00	0.00	0.00
2-Propanol	-1.74	-0.25	0.00	4.75	-0.45	-0.65	0.00	0.00	0.00	0.00	0.00	0.33	-0.20	0.00	0.17	-0.06	0.00	0.00	0.00	0.00
1-Propanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1-Butanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Formaldehyde	0.92	0.54	0.54	0.30	0.16	0.22	13.88	16.77	0.33	0.39	0.47	1.07	1.01	0.94	1.06	1.20	1.19	1.44	0.43	0.61
Acetaldehyde	0.35	0.18	0.18	0.10	0.01	0.04	5.31	6.25	0.14	0.10	0.16	0.26	0.33	0.28	0.00	0.40	0.16	0.21	0.20	0.25
Acrolein	0.00	0.00	0.01	0.00	0.00	0.00	0.77	0.82	0.00	0.00	0.02	0.05	0.24	0.18	0.03	0.04	0.00	0.06	0.01	0.00
Acetone	0.00	0.00	-0.86	0.00	0.00	0.00	-0.18	-0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.41	0.94	0.00	0.00	0.00
Propionaldehyde	0.00	-0.01	0.01	-0.01	-0.01	-0.01	-0.03	0.61	-0.01	-0.01	0.02	0.03	0.02	0.00	0.06	0.03	0.01	0.04	0.07	0.00
Crotonaldehyde	0.00	0.00	0.00	0.00	0.00	0.00	-0.44	-0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.03	0.00	0.04	0.00
Isobutyraldehyde	-0.01	-0.01	0.00	0.00	0.00	0.00	0.28	0.23	-0.01	-0.01	0.00	0.00	0.00	0.05	0.00	-0.01	0.00	0.00	0.01	0.00
MEK	-0.01	-0.01	0.00	0.00	0.00	0.00	0.28	0.23	-0.01	-0.01	0.00	0.00	0.00	0.05	0.00	-0.01	0.00	0.00	0.01	0.00
Benzaldehyde	0.09	0.04	0.01	0.17	-0.01	-0.01	0.49	0.24	0.03	0.03	0.33	0.38	0.26	0.09	0.17	0.18	0.04	0.09	0.09	0.03
Isovaleraldehyde	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	-0.01	0.02	0.03	0.00	0.00	0.00	0.11	0.00
Valeraldehyde	-0.03	-0.03	0.00	0.12	0.04	-0.01	0.06	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.09	0.00
o-Tolualdehyde	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.08	0.00	0.00	-0.05	0.01	0.00	0.01	0.00	0.01
m/p-Tolualdehyde	0.00	0.00	0.00	0.38	0.22	0.07	0.21	0.00	0.00	0.00	0.09	0.06	0.05	0.01	0.05	0.08	0.00	0.11	0.06	0.00
Hexanaldehyde	0.03	0.00	0.00	-0.01	-0.02	-0.02	0.24	0.00	0.00	0.00	0.01	0.04	-0.01	0.01	-0.04	0.03	0.00	0.04	0.02	0.04
Dimethylbenzaldehyde	0.00	0.00	0.00	0.36	0.13	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	-0.05	0.00	0.00	0.01	0.00
Nominal Limit of Detection	0.60	0.60	0.60	0.60	0.60	0.60	1.77	1.77	0.77	0.77	0.01	0.01	0.01	0.01	0.01	0.01	0.60	0.60	0.60	0.60

Footnotes: Negative values are due to background subtraction
Zero is reported if measurement is below the blank value

TABLE E-3. ENGINE C CARBONYLS AND ALCOHOLS

mg/hp-hr	FTP-w-1	FTP-w-2	FTP-w-3	FTP-wo-1	FTP-wo-2	FTP wo-3	CARBX-1	CARBX-2	CARBZ-1	CARBZ-2	16-hour-1a	16-hour-1b	16-hour-2a	16-hour-2b	16-hour-3a	16-hour-3b	TB-1	TB-2	TB-3	TB-4
Methanol	1.15	0.18	0.68	0.09	0.43	0.90	N/A	N/A	N/A	N/A	-0.02	0.12	0.21	0.20	0.85	0.10	0.00	0.59	0.84	0.49
Ethanol	1.44	0.89	0.00	0.00	0.19	0.31	N/A	N/A	N/A	N/A	-0.03	0.09	0.24	0.14	0.21	-0.05	0.00	0.00	0.00	0.50
2-Propanol	1.85	1.35	-0.48	0.04	0.43	0.94	N/A	N/A	N/A	N/A	-0.15	0.02	-0.12	0.01	0.31	-0.05	0.00	0.18	1.24	0.47
1-Propanol	0.00	0.00	0.00	0.00	0.00	0.00	N/A	N/A	N/A	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1-Butanol	0.00	0.00	0.00	0.00	0.00	0.00	N/A	N/A	N/A	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Formaldehyde	0.91	0.56	0.18	0.19	0.07	0.09	N/A	N/A	N/A	N/A	1.65	3.77	6.26	8.28	0.21	-0.13	0.79	0.00	0.42	0.00
Acetaldehyde	0.29	0.25	0.10	0.14	0.02	0.04	N/A	N/A	N/A	N/A	0.29	0.50	1.60	2.14	0.07	0.01	0.08	0.00	0.20	0.03
Acrolein	0.00	0.00	0.00	0.10	0.00	0.00	N/A	N/A	N/A	N/A	0.05	0.02	-5.73	0.11	-0.01	0.00	0.06	0.00	0.01	0.00
Acetone	1.25	0.04	0.00	0.00	0.00	0.00	N/A	N/A	N/A	N/A	-0.62	0.00	0.00	0.51	0.00	0.00	0.00	5.46	0.00	0.00
Propionaldehyde	0.00	0.00	0.00	0.00	0.00	0.00	N/A	N/A	N/A	N/A	0.02	-3.76	0.00	0.04	0.00	0.00	0.03	0.47	0.06	0.00
Crotonaldehyde	-0.19	-0.19	-0.19	0.00	0.00	0.00	N/A	N/A	N/A	N/A	0.00	0.00	0.00	-0.05	0.00	0.00	0.00	0.00	0.04	0.00
Isobutyraldehyde	0.00	0.00	0.00	0.00	0.00	0.00	N/A	N/A	N/A	N/A	-0.01	0.00	0.05	0.16	0.00	-0.02	0.03	0.00	0.01	0.00
MEK	0.00	0.00	0.00	0.00	0.00	0.00	N/A	N/A	N/A	N/A	-0.01	0.00	0.05	0.16	0.00	-0.02	0.03	0.00	0.01	0.00
Benzaldehyde	0.20	0.00	0.00	0.00	0.00	0.00	N/A	N/A	N/A	N/A	0.08	0.05	0.18	0.07	-0.01	0.00	0.37	0.11	0.09	0.00
Isovaleraldehyde	0.00	0.00	0.00	0.10	0.00	0.00	N/A	N/A	N/A	N/A	0.00	0.02	0.00	0.01	0.00	0.00	0.18	0.00	0.11	0.00
Valeraldehyde	0.08	0.17	-0.04	0.00	0.00	0.00	N/A	N/A	N/A	N/A	-0.08	0.08	-0.02	0.05	0.01	0.01	0.00	0.13	0.09	0.00
o-Tolualdehyde	0.00	0.00	0.00	0.00	0.00	0.00	N/A	N/A	N/A	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00
m/p-Tolualdehyde	0.54	0.33	0.09	0.00	0.00	0.00	N/A	N/A	N/A	N/A	0.02	0.08	0.00	0.06	0.00	0.00	0.00	0.17	0.06	0.00
Hexanaldehyde	0.07	0.00	0.00	0.20	-0.01	-0.01	N/A	N/A	N/A	N/A	0.03	0.05	-0.03	0.01	0.04	-0.02	0.00	0.00	0.02	0.00
Dimethylbenzaldehyde	0.00	0.00	0.00	0.28	0.00	0.00	N/A	N/A	N/A	N/A	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.17	0.01	0.00
Nominal Limit of Detection	0.60	0.60	0.60	0.60	0.60	0.60	1.77	1.77	0.77	0.77	0.01	0.01	0.01	0.01	0.01	0.01	0.60	0.60	0.60	0.60

Footnotes: Negative values are due to background subtraction
Zero is reported if measurement is below the blank value

TABLE E-4. ENGINE D CARBONLYS AND ALCOHOLS

mg/hp-hr	FTP-w-1	FTP-w-2	FTP-w-3	FTP-wo-1	FTP-wo-2	FTP wo-3	CARBX -1	CARBX -2	CARBZ -1	CARBZ -2	16-hour-1a	16-hour-1b	16-hour-2a	16-hour-2b	16 -hour-3a	16-hour-3b	TB-1	TB-2	TB-3
Methanol	0.46	0.35	0.39	-0.11	-0.10	0.57	4.78	4.01	-0.04	-0.05	0.02	-0.03	0.00	0.01	0.05	-0.06	0.32	0.44	0.60
Ethanol	0.00	0.00	0.47	0.52	0.34	0.18	0.89	2.97	-0.03	-0.06	0.08	-0.02	0.31	0.21	0.03	-0.04	0.41	0.00	0.00
2-Propanol	0.24	0.00	0.86	-0.76	1.11	0.08	6.82	-7.81	-0.16	0.16	0.09	0.01	-0.01	-0.02	0.05	0.02	0.29	0.57	0.42
1-Propanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1-Butanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Formaldehyde	0.35	0.40	0.37	0.47	0.33	0.32	57.91	29.58	-0.29	0.44	1.78	1.36	1.31	1.28	3.67	0.35	0.52	0.36	0.35
Acetaldehyde	0.16	0.16	0.15	-0.16	0.01	-0.04	20.64	10.81	-0.20	0.21	0.61	0.19	0.47	0.46	1.25	0.46	0.20	0.33	0.11
Acrolein	0.03	0.00	0.00	0.00	0.00	0.00	4.40	2.69	-0.01	0.00	0.06	0.13	0.03	0.08	0.19	0.07	0.04	0.00	0.00
Acetone	0.00	0.00	0.00	0.00	0.00	0.00	10.64	0.68	-0.07	0.07	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00
Propionaldehyde	0.00	0.00	0.00	0.00	0.00	0.00	2.13	1.51	0.00	0.00	0.01	0.00	0.01	0.00	0.00	-0.09	0.01	0.01	0.18
Crotonaldehyde	0.00	0.00	0.00	0.01	0.01	-0.08	6.12	3.87	-0.04	-0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Isobutyraldehyde	0.25	0.28	0.31	0.00	0.00	0.00	0.98	0.53	-0.02	0.08	0.06	0.03	0.17	0.04	0.00	0.00	0.00	0.06	0.59
MEK	0.24	0.29	-0.08	0.00	0.00	0.00	0.99	0.53	-0.03	0.08	0.07	0.04	0.17	0.04	0.00	0.00	0.00	0.06	0.00
Benzaldehyde	0.06	0.01	-0.03	0.15	0.31	0.24	1.81	0.63	0.00	0.03	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.11	0.00
Isovaleraldehyde	0.01	0.04	0.04	0.00	0.00	0.00	0.50	0.62	-0.01	-0.01	-0.01	0.00	0.00	-0.01	0.02	-0.01	0.03	0.02	0.00
Valeraldehyde	-0.05	0.03	-0.01	-0.02	-0.03	-0.04	0.79	0.92	-0.03	0.05	0.00	0.06	0.00	0.06	0.00	0.00	0.00	0.12	0.00
o-Tolualdehyde	0.00	0.00	0.00	0.00	0.00	0.00	1.20	0.68	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00
m/p-Tolualdehyde	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.15	0.00	0.00	0.05	0.03	0.00	0.09	0.09	0.00	0.00	0.04	0.00
Hexanaldehyde	0.02	0.00	0.00	0.02	0.00	0.00	0.32	0.03	0.00	0.00	0.00	0.01	0.01	-0.02	0.00	0.00	0.00	0.04	0.00
Dimethylbenzaldehyde	0.00	0.00	0.00	0.00	0.00	0.00	1.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00
Nominal Limit of Detection	0.60	0.60	0.60	0.60	0.60	0.60	1.77	1.77	0.77	0.77	0.01	0.01	0.01	0.01	0.01	0.01	0.60	0.60	0.60

Footnotes: Negative values are due to background subtraction
Zero is reported if measurement is below the blank value

APPENDIX F

NITROSAMINES

TABLE F-1. ENGINE A NITROSAMINES

	NDMA	NDMAU	NDEA	NDEAU	NDPA	NDPAU	NNMUR	NNMURU	NDBA	NDBAU	NPPD	NPPDU	NPYR	NPYRU	NMRP	NMRPU
	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr
FTP-w-1	0.0	3.1	0.0	2.6	0.0	1.3	0.0	31.5	0.0	8.4	0.0	4.4	0.0	5.4	0.0	17.1
FTP-w-2	0.0	3.2	3.9	2.6	0.0	1.3	0.0	31.8	0.0	8.5	0.0	4.5	0.0	5.5	0.0	17.3
FTP-w-3	0.0	3.3	3.7	2.7	0.0	1.3	0.0	32.7	0.0	8.7	0.0	4.6	0.0	5.6	0.0	17.7
FTP-wo-2	0.0	3.4	0.0	2.8	0.0	1.4	0.0	34.5	0.0	9.2	0.0	4.8	0.0	5.9	0.0	18.7
FTP-wo-3	0.0	3.0	0.0	2.5	0.0	1.2	0.0	30.5	0.0	8.1	0.0	4.3	0.0	5.2	0.0	16.6
FTP-wo-4	4.6	3.1	0.0	2.5	0.0	1.2	0.0	30.7	0.0	8.2	0.0	4.3	0.0	5.3	0.0	16.7
CARBX-1	15.2	20.9	43.7	17.6	22.8	9.7	0.0	209.9	0.0	56.0	0.0	29.4	0.0	36.1	0.0	114.0
CARBX-2	0.0	20.8	0.0	17.1	0.0	8.5	0.0	209.4	0.0	55.9	0.0	29.4	0.0	36.0	0.0	113.7
CARBZ-1	5.6	2.2	3.8	1.8	0.0	0.9	0.0	22.2	0.0	5.9	0.0	3.1	0.0	3.8	0.0	12.1
CARBZ-2	3.0	2.3	0.0	1.9	0.0	0.9	0.0	23.0	0.0	6.1	0.0	3.2	0.0	4.0	0.0	12.5
16-Hour-1	24.3	2.5	1.8	1.7	0.0	0.9	0.0	21.2	0.0	5.7	0.0	3.0	0.0	3.6	0.0	11.5
16-Hour-2	22.9	2.4	0.0	1.7	0.0	0.9	0.0	21.3	0.0	5.7	2.0	3.0	0.0	3.7	0.0	11.6
16-Hour-3	21.3	2.4	0.0	1.7	0.0	0.9	0.0	21.1	0.0	5.6	0.0	3.0	0.0	3.6	0.0	11.4
TB-1	0.0	3.2	0.0	2.6	0.0	1.3	0.0	31.9	0.0	8.5	0.0	4.5	0.0	5.5	0.0	17.3
TB-2	0.0	3.2	5.6	2.6	0.0	1.3	0.0	31.9	0.0	8.5	0.0	4.5	0.0	5.5	16.5	17.3
TB-3	0.0	3.2	2.2	2.6	0.0	1.3	0.0	31.9	0.0	8.5	0.0	4.5	0.0	5.5	0.0	17.3
TB-4	0.0	3.2	0.0	2.6	0.0	1.3	0.0	31.9	0.0	8.5	0.0	4.5	0.0	5.5	0.0	17.3

u is designated for measurement uncertainty or limit of detection
TB emissions is based on the FTP transient cycle information

TABLE F-2. ENGINE B NITROSAMINES

	NDMA	NDMAU	NDEA	NDEAU	NDPA	NDPAU	NNMUR	NNMURU	NDBA	NDBAU	NPPD	NPPDU	NPYR	NPYRU	NMRP	NMRPU
	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr
FTP-w-1	3.1	2.7	3.3	2.2	0.0	1.1	0.0	27.1	0.0	7.2	0.0	3.8	0.0	4.7	0.0	14.7
FTP-w-2	0.0	2.5	1.5	2.0	0.0	1.0	0.0	25.2	0.0	6.7	2.8	3.5	0.0	4.3	0.0	13.7
FTP-w-3	1.3	2.4	0.0	2.0	0.0	1.0	0.0	24.4	0.0	6.5	0.0	3.4	0.0	4.2	0.0	13.3
FTP-wo-2	0.0	2.6	3.2	2.1	0.0	1.1	0.0	26.0	0.0	6.9	0.0	3.6	0.0	4.5	0.0	14.1
FTP-wo-3	0.0	2.6	3.3	2.1	0.0	1.1	0.0	26.0	0.0	6.9	0.0	3.6	0.0	4.5	0.0	14.1
FTP-wo-4	0.0	2.6	2.6	2.1	0.0	1.1	0.0	26.0	0.0	6.9	0.0	3.6	0.0	4.5	0.0	14.1
CARBX-1	0.0	11.9	8.7	9.8	0.0	4.9	0.0	119.9	0.0	32.0	0.0	16.8	0.0	20.6	0.0	65.1
CARBX-2	0.0	11.8	0.0	9.7	0.0	4.8	0.0	119.0	0.0	31.8	0.0	16.7	0.0	20.5	0.0	64.6
CARBZ-1	2.7	1.8	2.5	1.5	0.0	0.7	0.0	17.6	3.7	4.7	0.0	2.5	0.0	3.0	0.0	9.6
CARBZ-2	3.0	1.8	1.7	1.5	0.0	0.7	0.0	18.4	0.0	4.9	0.0	2.6	0.0	3.2	0.0	10.0
16-Hour-1	15.4	2.4	5.0	1.9	0.0	0.9	0.0	22.8	0.0	6.1	0.0	3.2	0.0	3.9	0.0	12.4
16-Hour-2	13.3	2.4	5.7	1.9	0.0	0.9	0.0	22.7	0.0	6.1	0.0	3.2	0.0	3.9	0.0	12.3
16-Hour-3	11.5	2.3	4.7	1.9	0.0	0.9	0.0	22.7	0.0	6.1	0.0	3.2	0.0	3.9	0.0	12.3
TB-1	0.0	2.6	3.1	2.1	0.0	1.0	0.0	25.8	0.0	6.9	0.0	3.6	0.0	4.4	0.0	14.0
TB-2	0.0	2.6	2.7	2.1	0.0	1.0	0.0	25.8	0.0	6.9	0.0	3.6	0.0	4.4	0.0	14.0
TB-3	0.0	2.6	1.2	2.1	0.0	1.0	0.0	25.8	0.0	6.9	0.0	3.6	0.0	4.4	0.0	14.0
TB-4	0.0	2.6	0.0	2.1	0.0	1.0	22.6	27.1	0.0	6.9	0.0	3.6	0.0	4.4	0.0	14.0

u is designated for measurement uncertainty or limit of detection
TB emissions is based on the FTP transient cycle information

TABLE F-3. ENGINE C NITROSAMINES

	NDMA	NDMAU	NDEA	NDEAU	NDPA	NDPAU	NNMUR	NNMURU	NDBA	NDBAU	NPPD	NPPDU	NPYR	NPYRU	NMRP	NMRPU
	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr
FTP-w-1	84.9	139.1	0.0	113.7	0.0	56.9	0.0	1416.0	0.0	372.8	0.0	195.9	0.0	240.1	0.0	758.2
FTP-w-2	61.4	159.2	0.0	130.2	0.0	65.1	0.0	1621.8	0.0	426.9	0.0	224.3	0.0	275.0	0.0	868.3
FTP-w-3	74.3	154.1	0.0	126.1	0.0	63.0	0.0	1569.8	0.0	413.2	0.0	217.1	0.0	266.2	0.0	840.5
FTP-wo-2	88.6	172.4	0.0	141.0	116.3	74.3	0.0	1755.5	0.0	462.1	0.0	242.8	0.0	297.6	0.0	939.9
FTP-wo-3	51.4	160.0	0.0	130.9	0.0	65.5	0.0	1630.1	0.0	429.1	0.0	225.5	0.0	276.4	0.0	872.8
FTP-wo-4	98.2	160.9	0.0	131.6	0.0	65.8	0.0	1638.7	0.0	431.4	0.0	226.7	0.0	277.8	0.0	877.4
CARBX-1	160.2	311.7	0.0	254.9	721.0	196.0	0.0	3173.9	0.0	835.5	0.0	439.0	0.0	538.1	0.0	1699.4
CARBX-2	58.6	304.0	0.0	248.7	468.9	157.9	0.0	3096.4	0.0	815.1	0.0	428.3	0.0	525.0	0.0	1657.9
CARBZ-1	29.9	31.1	0.0	25.4	0.0	12.7	0.0	315.8	0.0	83.1	0.0	43.7	0.0	53.5	0.0	169.1
CARBZ-2	24.4	29.2	0.0	23.9	38.5	14.4	0.0	297.3	0.0	78.3	0.0	41.1	0.0	50.4	0.0	159.2
16-Hour-1	98.4	278.5	0.0	227.8	0.0	113.9	0.0	2797.2	0.0	746.8	35.8	392.4	0.0	481.0	0.0	1518.8
16-Hour-2	30.8	8.1	0.0	6.4	0.0	3.2	0.0	79.0	0.0	21.1	0.0	11.1	0.0	13.6	0.0	42.9
16-Hour-3	170.8	12.5	1.7	4.8	0.0	2.4	0.0	59.4	0.0	15.8	0.0	8.3	0.0	10.2	0.0	32.2
TB-1	39.3	81.4	0.0	66.6	0.0	33.3	0.0	829.4	0.0	218.3	0.0	114.7	0.0	140.6	0.0	444.1
TB-2	40.9	115.7	0.0	94.7	0.0	47.3	0.0	1178.7	0.0	310.3	0.0	163.0	0.0	199.8	0.0	631.1
TB-3	81.9	10.5	2.0	7.4	1.2	3.7	0.0	91.4	27.5	24.6	0.0	12.8	0.0	15.7	0.0	49.6

u is designated for measurement uncertainty or limit of detection
TB emissions is based on the FTP transient Cycle

TABLE F-4. ENGINE D NITROSAMINES

	NDMA	NDMAU	NDEA	NDEAU	NDPA	NDPAU	NNMUR	NNMURU	NDBA	NDBAU	NPPD	NPPDU	NPYR	NPYRU	NMRP	NMRPU
	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr	µg/hp-hr
FTP-w-1	0.0	32.6	0.0	26.7	0.0	13.3	0.0	334.7	0.0	87.5	0.0	46.0	0.0	56.3	0.0	177.9
FTP-w-2	0.0	33.2	0.0	27.1	0.0	13.6	308.1	349.3	0.0	89.0	0.0	46.7	0.0	57.3	0.0	180.9
FTP-w-3	22.5	36.9	10.7	30.2	8.3	15.2	0.0	380.0	0.0	98.9	0.0	52.0	0.0	63.7	0.0	201.1
FTP-wo-2	26.1	38.7	22.4	31.8	0.0	15.8	0.0	398.3	0.0	103.8	0.0	54.5	0.0	66.8	0.0	211.0
FTP-wo-3	0.0	90.5	0.0	74.1	0.0	37.0	692.6	949.6	0.0	242.8	0.0	127.6	0.0	156.4	0.0	493.8
FTP-wo-4	0.0	91.6	64.8	75.2	0.0	37.5	317.9	951.9	0.0	245.6	0.0	129.1	0.0	158.2	0.0	499.6
CARBX-1	0.0	439.1	324.6	360.7	0.0	179.6	1044.4	4554.2	0.0	1177.6	0.0	618.7	0.0	758.5	0.0	2395.2
CARBX-2	0.0	468.1	496.5	386.0	0.0	191.5	2256.8	4878.4	0.0	1255.4	0.0	659.6	0.0	808.6	0.0	2553.3
CARBZ-1	0.0	60.2	0.0	49.3	0.0	24.6	0.0	616.3	0.0	161.5	0.0	84.8	0.0	104.0	0.0	328.4
CARBZ-2	0.0	56.0	0.0	45.8	0.0	22.9	0.0	570.5	0.0	150.2	0.0	78.9	0.0	96.7	0.0	305.4
16-Hour-1	15.7	2.7	2.9	2.0	0.7	1.0	0.0	25.1	0.0	6.6	0.0	3.5	0.0	4.2	0.0	13.4
16-Hour-2	32.6	3.5	2.6	2.1	0.7	1.1	0.0	26.1	0.0	6.9	0.0	3.6	0.0	4.4	0.0	14.0
16-Hour-3	14.9	2.8	3.3	2.2	1.0	1.1	0.0	26.4	0.0	7.0	0.0	3.7	0.0	4.5	5.3	14.2
TB-1	0.0	88.7	0.0	72.6	0.0	36.3	0.0	909.2	0.0	238.0	0.0	125.0	0.0	153.3	0.0	484.0
TB-2	0.0	93.5	0.0	76.5	0.0	38.3	0.0	952.8	0.0	250.8	0.0	131.8	0.0	161.6	0.0	510.2
TB-3	0.0	648.0	0.0	530.2	0.0	265.1	7010.6	6892.8	0.0	1737.9	0.0	913.1	0.0	1119.3	0.0	3534.8

u is designated for measurement uncertainty or limit of detection
TB emissions is based on the FTP transient cycle information